AD-A115 176 NORSKE VERITAS OSLO F/G 13/10

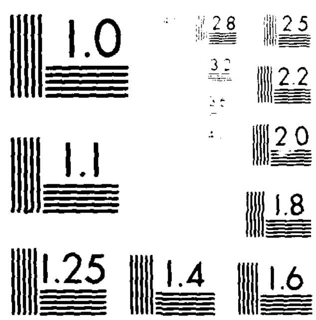
SUMMARY OF A COURSE IN SHIPHANDLING IN ROUGH WEATHER.(U)

SEP 81 K LINDEMANN DOT-CG-833401-A

UNCLASSIFIED 81-0782 USCG-M-7-81 NL

1 OF 2

AD A
115176



MICROCOPY RESOLUTION TEST CHART

AD A115176

U.S. Department
of Transportation
United States
Coast Guard

Summary of a Course in Shiphandling in Rough Weather

Kaare Lindemann

Det norske Veritas

This document is available to the public
through the National Technical Information
Service, Springfield, Virginia 22161.

Office of Merchant Marine Safety
Washington DC 20593

September 1981
Final Report

CG-M-7-81

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-M-7-81	AD-A115176	

4. Title and Subtitle
Summary of a Course in Shiphandling in Rough Weather

5. Report Date
September 1981

6. Performing Organization Code
54 (54 30 00)

7. Author(s)
Kåre Lindemann

8. Performing Organization Report No.
81-0782

9. Performing Organization Name and Address
Det norske Veritas
P.O. Box 300, Høvik, N-1322
Oslo, Norway

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DOT-CG-833401-A

12. Sponsoring Agency Name and Address
U.S. Coast Guard (G-MTH-4/13)
2100 Second Street, S.W.
Washington, D.C. 20593

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
This project was performed as part of an interinstitutional research program aimed at improving the safety of crew, ship, and cargo when sailing in rough weather through the use of response instrumentation.

16. Abstract

The S03-project has been a research project working to improve ship handling procedures in a seaway. Both the field of instrumental aids and improved education have been given attention. The project has been sponsored by Norwegian interests, but was also supported by the U.S. Coast Guard. This report which is a continuation of the S03-project effort, summaries the content of a course for mariners in ship handling, sponsored by the U.S. Coast Guard at the U.S. Merchant Marine Academy, Kings Point on 24-25 March 1981.

The report gives in more detail the background for the course, an abstract of the course content, and a summary of the lecture notes.

In addition the course schedule and list of participants are given together with a rating of the course as given by the participants.

Two other reports are appended this volume as well, e.g. a S03-project report on: "Ship Handling in Rough Weather", and a SNAME spring meeting publication (1980); "Status Report on the Application of Stress and Motion Monitoring in Merchant Vessels".

17. Key Words
Seakeeping, Training, Ship motions, Dynamic loading, Wave-induced loads, Wave phenomena, Shiphandling, Instrumentation

18. Distribution Statement
Document is available to the U.S. public through the National Technical Information Service, Springfield,VA,22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	146	

Det norske Veritas
Research Division

POSTAL ADDRESS: P.O.BOX 300, 1322 HØVIK, NORWAY — TELEPHONE: +47(02) 12 99 55
CABLE ADDRESS: VERITAS, OSLO — TELEX: 16 192 VERIT N

TECHNICAL REPORT

VERITAS Report No.: 81-0782	Subject Group:
Date: September 1981	
Department: 54	Project No.: 54 30 00
Title of Report: SUMMARY OF A COURSE IN SHIPHANDLING IN ROUGH WEATHER	Approved by: Kåre Lindemann for Det norske Veritas Kåre Lindemann Princ. Res. Engineer
Client/Sponsor of project: U.S. COAST GUARD Contract DOT-CG-833401-A	Client/Sponsor ref.: H.P. Cojeen
Work carried out by: K. Lindemann	Reporters sign.: Kåre Lindemann

Summary

The S03-project has been a research project working to improve ship handling procedures in a seaway. Both the field of instrumental aids and improved education have been given attention. The project has been sponsored by Norwegian interests, but was also supported by the U.S. Coast Guard. This report which is a continuation of the S03-project effort, summaries the content of a course for mariners in ship handling, sponsored by the U.S. Coast Guard at the U.S. Merchant Marine Academy, Kings Point on 24-25 March 1981.

The report gives in more detail the background for the course, an abstract of the course content, and a summary of the lecture notes.

In addition the course schedule and list of participants are given together with a rating of the course as given by the participants.

Two other reports are appended this volume as well, e.g. a S03-project report on: "Ship Handling in Rough Weather", and a SNAME spring meeting publication (1980); "Status Report on the Application of Stress and Motion Monitoring in Merchant Vessels".

4 Indexing terms

- SEAKEEPING COURSE
- WAVE PHENOMENA
- WAVE INDUCED MOTIONS
- SHIP HANDLING

Distribution statement:

- [ ] No distribution without permission from the responsible department.
- [ ] Limited distribution within Det norske Veritas.
- [X] Free distribution.

Date of last rev.	Rev. No.	Number of pages

CONTENTS: PAGE:

1. BACKGROUND

Mariners have been exposed to many technological improvements helping him to meet the challenges of operating a modern ship. In Norway consern are given to the task of ship handling in rough weather, and ship motion and load monitoring and guidance units are under development.

From full scale trials of such equipment it became evident that what seemed obvious to the technical people who developed the system, was unfamiliar knowledge to the mariner. What believed to be useful information turned out to be confusing information and consequently was not put to use as anticipated.

Realizing this, it became clear that the mariners expected to apply or participate in the full scale trials of the equipment needed training.

Thought was given to what kind of training was necessary, and the list of following subjects was derived:

- Regular and irregular wave theory
- Characteristics of wave induced motions and loads
- Principles of hull motion monitoring
- Introduction to and principles of operation of a hull motion monitoring system
- Practical use of hull motion monitoring instrumentation
- Guidelines for ship handling in waves

The subjects should be taught in such a detail that it would cover at least 5 full day sessions.

However, the shipowners operating ships equipped with the prototype units of hull motion monitoring and guidance units could not afford more than one day of training for their ship mates.

Consequently the material was condensed to a one day seminar and taught to

all mates scheduled to ride with the prototype test ships.

The course was offered a total of 15 times, and created a considerable interest for the topic's, creating an equivalent interest for the course at the Norwegian merchant marine academies. Thus in response to their interest extracts of the course was offered two times at the merchant marine academy in Tønsberg and once at the academy in Ålesund.

The U.S. Coast Guard stimulated to the course through their active support and engagement in the Norwegian research project working to improve ship handling in rough weather by instrumental ship born monitoring and guidance units, the S03-project.

The Coast Guard wanted to take advantage of the existing course material and the teaching experience by offering a demonstration course for masters and mates from selected companies in the U.S. who are operating vessels with response monitoring instruments.

The course content as offered in the U.S. touched on the following subjects:

II. ABSTRACT OF U.S. COURSE CONTENT

The following is a detailed list of the content of the Coast Guard sponsored course. The reader is referred to Chapter VII for more details where a short summary of the lecture notes is given.

Regular wave theory: An introduction to sinusoidal gravity waves, demonstrating the relationship between wave-length, -period and velocity. Possible relationship between wave-height and wave-length leading to the consept of breaking waves. The energy content of a moving wave is introduced. Special wave phenomena, such as waves riding on top of currents, reflected waves and shallow water effects and refractions were shortly dealt with.

Irregular waves: The consept of irregular waves composed of infinitely many regular waves of different wave-height, wave-period and phase are introduced. The statistical description of the wave surface are brought forward together with the Rayleilgh distribution of wave-heights. The special features of the Rayleigh distribution are dealt with and the concept of extreme value distribution are presented. The representation of an irregular wave system in a wave-energy spectrum are shown. Special features of the wave spectrum is demonstrated such as wind driven seas, composed spectra, swell spectra etc. The special wave phenomena occurring off the coast of South Africa are explained, the same is the case for the steep waves some times experienced off the coast of Portugal.

Wave induced motions and loads: The idea of representing the ship/wave interaction as a mass, spring, damper system is presented. The characteristics of the six basic motions (roll, sway, yaw, heave, pitch, surge) are presented, together with the RAO - Response Amplitude Operator. The influence of wave-heading and ship speed on the RAO's are demonstrated, together with the effect of reballasting the ship. A special dynamic stability phenomena are discussed, i.e. parametric excited roll motion. The wave induced loads and their dependance on load-condition, and ship design parameters are discussed. Special phenomenon such as springing, whipping, slamming and green seas were not found time for in this course but would have been discussed in a longer course.

Hull Surveillance Instruments: The basic principles of hull surveillance instruments are shown. Distinction between guidance, monitoring and trend-analysis are made. The technological level for such instrumentation today is discussed.

Use of Hull Surveillance Instruments: Practical user experience with hull motion and load monitoring instruments are discussed, together with typical areas of application.

Ship handling in rough weather: Basic principles of ship handling procedures in rough weather are discussed. The importance of evaluating the relationship between wave-length and ship-length before deciding on measures to be taken are pointed out. The use of ship handling guidance charts are demonstrated.

III. THE U.S. COAST GUARD SPONSORED COURSE

The above mentioned course was offered at the Merchant Marine Academy, Kings Point on 24 and 25 March 1981 and the class schedule was as follows:

Tuesday 24 March

0900-1000	Check in and organization
1000-1015	Welcome by Commodore H. Casey
1015-1100	Session A
1115-1200	Session B
1215-1330	Lunch
1400-1445	Session C
1515-1600	Session D
1615-1700	Session E

Wednesday 25 March

0900-0930	Organization
0945-1045	Session F
1100-1200	Tour of CAORF (Computer Aided Operations Research Facility-manoeuvring simulator)
1215-1315	Lunch
1330-1430	Session G

Session A: Regular Wave Theory
Session B: Problem solution
Session C: Irregular wave theroy
Session D: Problem solution
Session E: Wave induced motions and loads, problem solution
Session F: Hull Surveillance Instruments and their practical use
Session G: An introduction to ship handling in rough weather. Films. Problems.

IV. LIST OF PARTICIPANTS AND OBSERVERS

Participants: Captain J.P. Aastrand
Farrell Lines, Incorporated
Deck Department
1 Whitehall Street
New York, N.Y. 10004
(212) 440-4200

Captain B. Barsanti
Exxon International
Supply & Transportation
1251 Ave. of the Americas
New York, N.Y. 10020
(212) 398-4279

Mr. John K. Bobb
Maritime Institute of Technology and Graduate Studies
Deputy Director
5700 Hammonds Ferry Road
Linthicum Heights, MD. 21090
(301) 636-5700

Cdr. Buckley
Mass. Maritime Academy
Marine Transportation
Academy Drive
Buzzards Bay, MA. 02532
(617) 759-5761

Captain George L. Cary
American President Lines
Chief Officer, Relieving Master
SS PRESIDENT JEFFERSON

7728 N.E. North Street
Bainbridge Island, WA 98110
(206) 842-4540

Cdr. Don Casey
U.S. Coast Guard
Third Coast Guard District
Operations, Chief Readiness Branch
CCGD 3(OR) Governors Island
New York 10004
(212) 668-7186

Captain J.L. Fear
U.S. Coast Guard
Commander, Third Coast Guard Dist. (O)
Governors Island
New York 10004
(212) 668-7069

Captain John M. Gibbons
Mass. Maritime Academy
Marine Transportation
Academy Drive
Buzzards Bay, MA. 02532
(617) 759-5761

Cdr. Ted Haendel
Nautical Science Dept.
U.S. Merchant Marine Academy
Kings Point, N.Y. 11024
(516) 482-8200

Captain Thomas H. McCarthy
Farrell Lines, Incorporated

Marine Department
1 Whitehall Street
New York, N.Y. 10004
(212) 440-4431

Cdr. Robert Meurn
Nautical Science Dept.
U.S. Merchant Marine Academy
Kings Point, N.Y. 11024
(516) 482-8200

Mr. Tom Nolan
Maritime Institute of Technology and Graduate Studies
Shiphandling Course (SHC)
5700 Hammonds Ferry Road
Linthicum Heights, MD. 21090
(301) 636-5700

Cdr. Richard J. Sandifer
New York State Maritime College
Executive Officer
Training Ship Empire State
Fort Schuyler
Bronx, New York 10465
(212) 892-3000

List of observers:

H. Paul Cojeen
U.S. Coast Guard (G-MMT-4/13)
Office of Merchant Marine Safety
2100 Second Street, S.W.
Washington, D.C. 20593
(202) 426-2197

Mr. Vince Fitzgerald
Hoffman Maritime Consultants
9 Glen Head Road
Glen Head, N.Y. 11545
(516) 676-8499

Dr. Walter M. Maclean
National Maritime Research Center
Kings Point, N.Y. 11024
(516) 482-8200

Mr. Charles B. Walburn
Bethlehem Steel Corporation
Marine Division
P.O. Box 6656
Sparrows Point, MD. 21219
(301) 388-7880

Captain James A. Wilson
Lake Carriers Association
Director of Training
1411 Rockefeller Building
Cleveland, Ohio 44113
(216) 621-1107

V. A RATING OF THE COURSE

It was of particular interest to rate the interest for the course from the participants. In that connection the attendants were asked to give their evaluation of the course using the rating sheets reproduced on the following pages:

SHIP HANDLING IN ROUGH WEATHER

Merchant Marine Academy, Kings Point, NY March 24-25, 1981

We will like to have your rating of the course. You are asked to evaluate the material covered and your benefit from it.

Use a rating from 5 to 1 where 5 means high value or very interested. 1 means no value or not interested. Put an x in the appropriate place.

DAY	TIME	TOPIC	INTEREST					BENEFIT				
			5	4	3	2	1	5	4	3	2	1
24	9-11	REGULAR WAVES										
24	11-12	PROBLEM SOLUTION REGULAR WAVES										
24	13-15	IRREGULAR WAVES										
24	15-16	PROBLEM SOLUTION IRREGULAR WAVES										
24/25	16-17 9-10	WAVE-INDUCED MOTIONS AND LOADS										
25	11-12	PROBLEM SOLUTION WAVE-INDUCED MOTIONS AND LOADS										
25	13-15	HULL-SURVEILLANCE INSTRUMENT										
25	15-16	ROUGH WEATHER GUIDANCE										
25	16-17	EXAMPLES/QUESTIONS										

QUESTION NUMBER	QUESTION	SCORES 5	4	3	2	1
1	How do you judge your own knowledge in seakeeping and ship handling in waves					
2	How are your interest for seakeeping theory and ship handling in waves					
3	How do you rate your need for seakeeping theory					
4	How important do you believe seakeeping experience is prior to becoming a master					
5	How strongly do you feel that seakeeping theory and ship handling in waves should be teached at school					
6	How valuable do you believe a motion monitoring system will be to you					
7	How valuable do you believe a prediction system will be to you					
8	How valuable do you believe an optimum speed course predictor will be to you					
9	How do you rate this course					
14	If yes on question no. 13, how simple was it to operate					

QUESTION NUMBER	QUESTION	YES	NO
10	Have you had any seakeeping theory at school		
11	Do you believe that seakeeping theory should replace other subjects teached at merchant academies		
12	Do you believe that seakeeping theory should be added on your present theoretical education		
13	Have you sailed with a hull surveillance system		

Questionare

15. Have you experienced heavy weather problems in following seas?

16. Have you experienced conditions at sea when the vessel did not responded as expected to changes in speed and/or course?

17. How many years have you been at sea?

18. What was not covered in sufficient detail on the course?

19. What was covered in too much detail?

20. Other comments.

The following is a summary of how the participants responded to the course: where the number in the appropriate box indicates how many had checked that box

DAY	TIME	TOPIC	INTEREST					BENEFIT				
			5	4	3	2	1	5	4	3	2	1
24	9-11	REGULAR WAVES	5	6	1	0	1	3	5	4	1	0
24	11-12	PROBLEM SOLUTION REGULAR WAVES	5	6	2	0	0	4	6	3	0	0
24	13-15	IRREGULAR WAVES	7	6	0	0	0	5	4	3	1	0
24	15-16	PROBLEM SOLUTION IRREGULAR WAVES	8	3	0	1	1	4	2	5	1	1
24/25	16-17 9-10	WAVE-INDUCED MOTIONS AND LOADS	10	3	0	0	0	7	3	1	1	0
25	11-12	PROBLEM SOLUTION WAVE-INDUCED MOTIONS AND LOADS	8	4	0	0	0	4	4	3	1	0
25	13-15	HULL-SURVEILLANCE INSTRUMENT	7	3	3	0	0	5	3	2	2	0
25	15-16	ROUGH WEATHER GUIDANCE	11	2	0	0	0	8	1	1	2	0
25	16-17	EXAMPLES/QUESTIONS	7	3	1	0	0	6	2	2	0	0

QUESTION NUMBER	QUESTION	SCORES 5 4 3 2 1
1	How do you judge your own knowledge in sea-keeping and ship handling in waves	3 4 4 2 0
2	How are your interest for seakeeping theory and ship handling in waves	9 4 0 0 0
3	How do you rate your need for seakeeping theory	7 5 1 0 0
4	How important do you believe seakeeping experi-ence is prior to becoming a master	12 1 0 0 0
5	How strongly do you feel that seakeeping theory and ship handling in waves should be teached at school	10 2 1 0 0
6	How valuable do you believe a motion monitoring system will be to you	5 6 1 0 1
7	How valuable do you believe a prediction system will be to you	4 7 1 0 1
8	How valuable do you believe an optimum speed course predictor will be to you	4 7 1 0 1
9	How do you rate this course	7 4 2 0 0
14	If yes on question no. 13, how simple was it to operate	0 1 1 0 0

QUESTION NUMBER	QUESTION	YES	NO
10	Have you had any seakeeping theory at school	6	7
11	Do you believe that seakeeping theory should replace other subjects teached at merchant academies	7	
12	Do you believe that seakeeping theory should be added on to your present theoretical education	12	
13	Have you sailed with a hull surveillance system	3	10

The following statements summarize the response to questions no. 15-20.

15. - yes definitely
    - yes including Typhoons and Hurricanes
    - yes, almost on every Transpacific voyage
    a total of 11 yes'es

16. - often
    - seldom
    - a few times
    a total of 10 yes'es

17. - 10 years
    - 35 "
    - 4 "
    - 14 "
    - 5 "
    - 35 "
    - 7 "
    - 10 "
    - 15 "
    - 12 "
    - 10 "
    - 35 "

18. - practical information, utilization of training aids
    - practical application for operators
    - problems could have been substituted by worked out examples
    - more practical applications
    - manoeuvring of ships in heavy weather
    - stability, flume and gyro-stabilization
    - application of theory
    - wave problem solution
    - more deails in problem solution
    - theoretical background

19. - matehmatics and math problems
    - initial introduction
    - equation solution
    - too much research oriented viewpoints

20. - more rules of the thumb
    - course not long enough
    - from an operator's point of view, too technical
    - did not come equipped for problem solving
    - anticipated a demonstration of equipment
    - a very good and beneficial first effort in an area needing more attention
    - some of the "sept of the pants, sole of the foot" type changes in course and speed that I have been engaged in over the years were explained
    - please develop the course more
    - the practical applications are fascinating
    - could have been longer
    - a lot of the materials presented was interesting and new to me
    - it will be of value to me in the future
    - basic consepts were excellent. However, in 1½ days time it is impossible to develop sufficient background to apply concepts intelligent
    - more simplified approach gradually building to detail

In general it must be concluded that the course was a success, but more time should have been spent on the individual topics, in particular those related to practical ship handling. However, the course was well accepted indicating that it very well could be repeated and hopefully be developed further to satisfy the need of sailing masters and mates.

V. PROBLEMS

1. A wave has a period of 8 seconds. How long is the wave-length? At what speed does it travel? What is the maximum possible height of the wave? Ans: 99.8 m, 12.5 m/sec, 14.3 m.

2. A ship is sailing in following seas (β = 180°) and observes a wave period of 6 seconds. How fast must the ship run in order to obtain the same speed as the wave? Ans.: 18.3 knots.

3. A ship is sailing in quart following seas (β = 135°). The wave length is 75 m. How fast should the ship run in order to be stationary positioned in the waves? Ans.: 29.7 knots.

4. A ship has a natural pitch period of 8 seconds, and sails at 18 knots in head seas (β = 0°). The wave period is 7 seconds. How will a speed reduction influence on the ships pitch motion. Ans.: Increased motions.

5. A ship has natural roll period of 12 seconds and sails in beam seas (β = 90°) at 14 knots with a wave period of 14 seconds. How will a speed reduction influence on the ships roll motion? By changing the course to β = 120° how will this influence on the roll motion. Ans.: None. Reduced motions.

6. We have observed 175 consecutive waves. The highest of these was estimated to 8.5 meter. What is the significant wave-height? Ans.: 5.3 meter.

7. The following consecutive wave-heights are observed: 13.4, 11.1, 4.9, 7.8, 3.3, 1.2, 4.8, 11.6, 15.7, 8.9, 11.0, 7.3, 6.5, 8.1, 5.1, 4.9, 3.1, 1.3, 0.8, 5.8, 3.6, 6.3, 11.3, 12.2, 10.1, 4.2, 5.8, 8.0, 12.1, 9.0, 6.8, 6.8, 4.7, 6.3, 6.5, 6.4, 2.7 all numbers in meters. What is the significant wave-height? The following wave periods are associated with the above corresponding

wave-heights: 11.3, 10.6, 12.5, 8.1, 5.0, 6.9, 6.3, 11.3, 10.0, 12.5, 8.8, 12.5, 11.2, 10.0, 10.0, 5.0, 5.6, 3.7, 2.5, 6.3, 6.3, 7.5, 8.7, 10.1, 12.5, 6.3, 8.7, 5.6, 11.2, 10.6, 10.5, 12.5, 12.5, 10.0, 11.3, 10.0, 11.3 all numbers in seconds. What is the average wave period? What is the significant steepness? Ans.: H_s = 11.2 m, T = 9.1 sec, s = 0.087.

8. The significant wave-height H_s = 4.0 meter and the average wave-period is 7 seconds. What will be the maximum wave-height within 1 hour? 5 hours? Ans.: 7.1 m, 7.9 m.

9. A ship has a beam of 30 m and operates with a GM = 3.0 m. Give an estimate of the roll resonance period. Ans.: 11.6 seconds.

VI. SUMMARY OF LECTURE NOTES

1.0 Regular wave theory

A sinusoidal wave is shown in Fig. 1. The basic wave definitions such as wave height H, the wave amplitude a, the wave length λ and the wave-period T are shown on the figure. In addition we often talk about the angular frequency defined as

$$\omega = 2\pi / T$$

and the wave-steepness

$$s = H/\lambda$$

For regular gravity waves, the wave period is related to the wave-length by the following relationship

$$T = \sqrt{2\pi\lambda/g}$$

where the acceleration of gravity g = 9.81 m/s^2 [32.2 ft/s^2] or

$$\lambda = gT^2/2\pi = 1.56T^2 \ [m]$$

The speed of the wave itself is defined as

$$C = \lambda/T = 1.56\ T\ [m/s]$$

For shallow waters, when the water depth $d < \lambda/25$ the wave speed becomes constant

$$C = \sqrt{g\ d}$$

Some characteristics of deep water gravity waves are shown in the following table. (Note: multiple speed (in m/sec) by 1.94 to obtain speed in knots)

Wave length m	Wave speed m/sec	Wave period sec	Max stable wave height m
10	3.95	2.53	1.43
20	5.59	3.58	2.86
30	6.84	4.39	4.29
40	7.90	5.06	5.71
50	8.84	5.66	7.14
75	10.82	6.93	10.71
100	12.50	8.01	14.29
125	13.97	8.95	17.86
150	15.30	9.81	21.43
175	16.53	10.59	25.00
200	17.67	11.32	28.57
225	18.74	12.01	32.14
250	19.76	12.66	35.71
275	20.72	13.28	39.29
300	21.64	13.87	42.86
350	23.30	14.98	50.00
400	24.99	16.01	57.14
450	26.51	16.98	64.29
500	27.94	17.90	71.43
600	30.61	19.61	85.71
700	33.06	21.18	100.00
800	35.34	22.65	114.30
900	37.49	24.02	128.60
1000	39.51	25.32	142.90

The wave energy may be expressed as

$$E = \frac{1}{8} \rho g H^2$$

per unit area

where ρ is the water density [Kg/m^3] . (The energy is equally divided between potential and kineitic energy). The kinetic energy of the wave is among other related to the water particles velocities within the wave. The particle velocity may be expressed as

$$C_p = \frac{H}{2} \sqrt{2\pi \ g/\lambda} \ \cos \left(\frac{2\pi \ ct}{\lambda} \right)$$

at deep water on the surface. Hence it can be seen that the particle motion is circular in a wave, and has its maximum velocity at the wave crest and minimum in the through. When the particle speed C_p becomes larger than the wave speed, the wave will breake. For a given wave-length the particle velocity will increase with wave-height. As a rule we may say that the wave will break when

$$H/\lambda > 1/7$$

By considering the particle velocity, we may also deduce that a breaking wave is more dangerous than a stable wave of the same height. This is the case since the breaking wave has larger particle velocity, and as such contains more kinetic energy being a potential danger to a structure.

1.1 Wave/current interaction

A wave riding in the top of a current, and in the same direction tends to transfer energy to the current. I.e. the waves will in principle be smaller. On the contrary if the wave direction opposes the current, energy is transferred from the current to the waves, making them larger e.g.

steeper. The energy transfer is dependant on the wave-length and most energy transfer takes place for the shorter waves.

1.2 Shallow water effect

When a deep water gravity wave approaches the shore line, its phase velocity C is reduced and the wave-height is increased to maintain an energy balance (total energy is the same). The wave-length remains unchanged resulting in steeper waves.

1.3 Reflected waves

When a gravity wave hits a vertical or steep shore-line some of the wave energy is reflected. Such a reflected wave will at some instances create sudden "upswells" resulting in complex shaped waves which often break . Such a phenomena may be observed off the coast of Portugal.

1.4 Refracted waves

We noted for shallow waters that the wave phase velocity became constant for all wave-lengths at a given depth. The waves will then be refracted and tend to be parallel with the bottom contour, in some cases creating wave energy-consentration such as often may occur outside a cape.

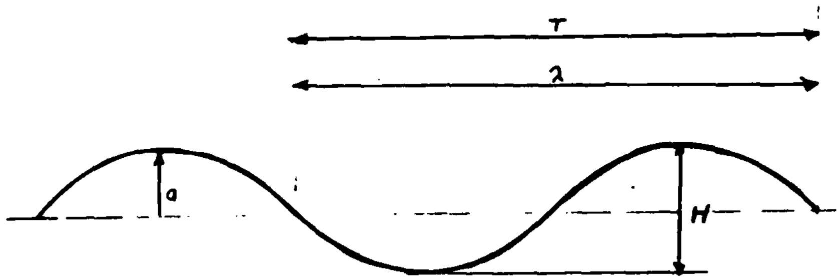


FIG. 1 Regular gravity wave

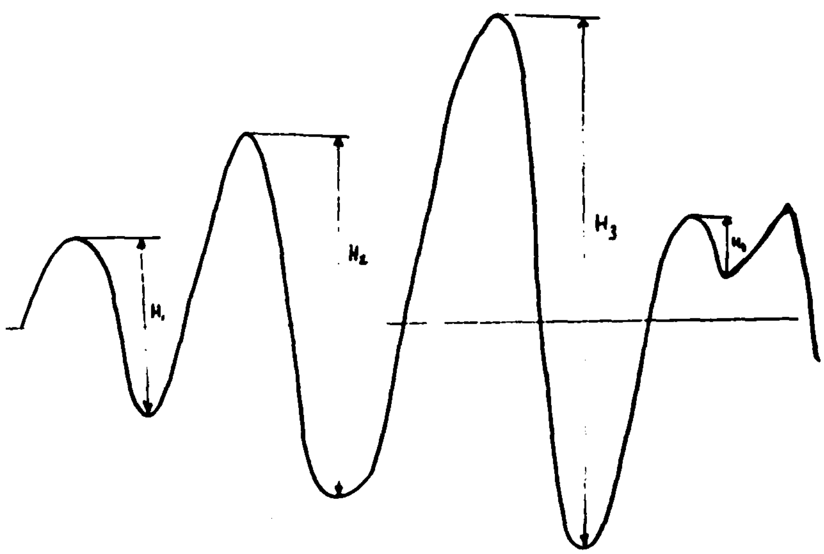


FIG. 2 Irregular Wave Record

2.0 Irregular wave theory

As noted, waves of different wave-length travels at different speeds. Longer waves travels faster than shorter waves, hence if we consider a wave system composed of infinitely many individual sinusoidal waves of different height, length and phase, the longer waves will over-run the shorter waves creating an irregular surface with some waves acting together in one instance, creating a tall wave for in the next instance to die out again.

This confused wave pattern can only be treated with statistical methods. Statistics is not an exact science. That is, whatever we analyze with statistical tools will only tell us an expected result, but this may not be the final. However, by statistical tools we are able to say that certain events will happen, with a confidence of say 99%.

But let us see how such methods are applied in practise by analyzing the confused wave-pattern composed of a variety of wave-heights. Let us assume that we in some way (wave bouy, wave staff, etc.) have been able to obtain a time history plot of how the wave surface moves up and down at a certain point (Fig. 2).

Our task is to tell something about the experienced wave-heights. By inspecting the record we are able to pick out the individual wave-heights. These heights say: 13.4 m, 11.1 m, 4.9 m, 7.8 m etc. (see problem 7) we sort into certain wave groups as shown in the following table.

WAVE-HEIGHT INTERVAL [m]	NUMBER OF OBSERVATIONS	FREQUENCY OF OCCURRENCE	WAVE-HEIGHTS INTERVAL/H_s
0.0 - 2.8	59	0.118	0.0 - 0.25
2.8 - 5.7	138	0.276	0.25 - 0.50
5.7 - 8.5	141	0.282	0.50 - 0.75
8.5 -11.3	95	0.190	0.75 - 1.00
11.3 -14.1	46	0.092	1.00 - 1.25
14.1 -17.0	16	0.032	1.25 - 1.50
17.0 -19.8	4	0.008	1.50 - 1.75
19.8 -22.6	1	0.002	1.75 - 2.00

Out of 500 consecutive observed waves, we found 59 which ranged in height from 0.0 meter to 2.8 meter. 138 waves fell in the group of 2.8 meter to 5.7 meter ect. For each of these wave groups we may define what we call the frequency of occurrence.

Defined as

$$f = \frac{\text{number in one group}}{\text{total number of observations}} = \frac{n_i}{N}$$

For the first group, [0 - 2.8 m] this number will be $f_1 = 59/500 = 0.118$, for the second group $f_2 = 138/500 = 0.276$ etc.

By multiplying these numbers by 100% we obtain $f_1 = 11.8\%$, $f_2 = 27.6\%$, $f_3 = 28.2\%$, etc. Now we may say that for this wave record or condition there is an 28.2% chance for that the experienced waves will be in the range of 5.7 - 8.5 meter.

If we sum $f_1 + f_2 + f_3 = 11.8\% + 27.6\% + 28.2\% = 67.6\%$ we may say that 67.6% of the observed waves will be equal to or less than 8.5 meter. Or in the other side 100% - 67.6% = 32.4% of the waves will be larger than 8.5 meter.

If we had observed the wave system, we should pick the larger well-formed waves h_i and estimte the average of these

$$H_v = (h_i + h_{i+1} + h_{i+2} + \ldots + h_{i+9})/10$$

this is our observed wave-height. This number turned out to be 11.3 meter. We will now take this observed wave-height (significant wave-height H_s) and make the wave-height intervals non-dimensional. I.e.

$$\frac{0.0}{11.3} = 0, \quad \frac{2.8}{11.3} = 0.25, \quad \frac{5.7}{11.3} = 0.5 \quad \text{etc.}$$

Using this we may construct a new "non-dimensional" wave-height group interval. (Column 4 in the table).

We are now ready to make a graphic representation of our observations. On the abscissa (horizontal axis) we plot the non-dimensional wave intervals, and on the ordinate (vertical axis) the frequency of occurrence, as shown in Fig. 3.

This procedure could have been repeated for several independent wave observations, and we would have ended up with approximately the same diagram, irrespective of the observed wave-height was 3 or 15 meter.

Hence, we have established that the wave-heights in a wind-driven sea state follow a fixed statistical pattern. The shape of the frequency distribution diagram in Fig. 3 may be approximated by a mathematical function, termed the Rayleigh distribution function.

$$f(H) = 4H/H_s \exp\left\{-2(H/H_s)^2\right\}$$

By integrating this equation we obtain the Rayleigh probability function

$$F(H^*) = Pr(H < H^*) = 1 - \exp\left\{-2(H^*/H_s)^2\right\}$$

which tells us that the probability that a wave-height is equal to or less than H^* in a wave system with wave-height H_S.

For example with H_S = 6 meter, what is the probability for that the wave-heights are less than 10m? Using the Rayleigh distribution function we obtain

$$Pr(H<10) = 1 - \exp\{-2(10/6)^2\}$$

or 99.6%.

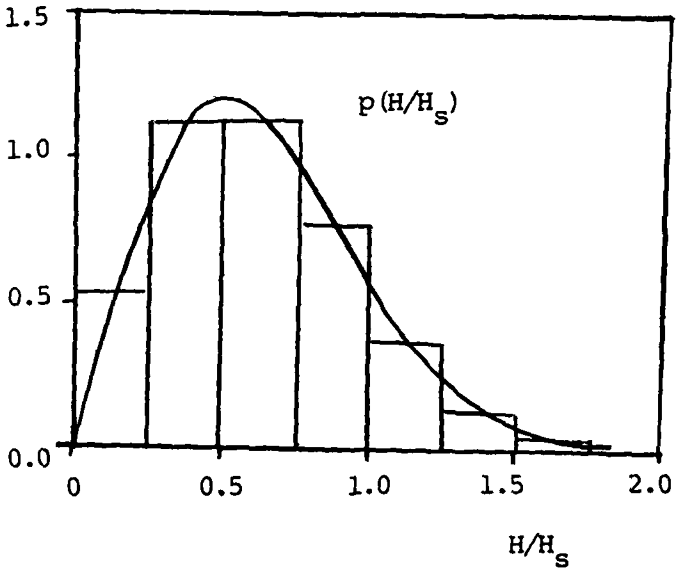


FIG. 3 The Rayleigh-distribution, Wave histogram.

On the other side we may want to know, what is the chance that the waves will exceed H_S. This we term as follows,

$$Q(H > H_S^*) = 1 - F(H^*) = \exp\{-2(H/H_S)^2\}$$

and returning to our example, with H_S = 6 m we find

$$Q(H > 10) = \exp\{-2(10/6)^2\} = 0.004$$

or a 0.4% chance for that the waves will exceed 10 meter.

We may now ask, how large may a wave be in a given wave system. Using the Rayleigh distribution we may derive the following expression.

$$H_{max} = H_s \sqrt{\ln N/2}$$

where N is the number of encountered waves. Hence for N ~ 2980, H_{max} = $2H_s$ which we use as a rule of the thumb.

RULE: The maximum wave-height in a wave system is approximately 2 times that of the observed wave-height. In general, this will be a conservative estimate.

We may now introduce a general property of the Rayleigh distribution, the average wave-height

$$\overline{H} = \sqrt{\frac{\pi}{2}}\,\frac{H_s}{2} = (H_1 + H_2 + H_3 + \ldots + H_N)/N$$

However, this concept is of less practical value, but must be applied to solve problem 7.

If we in Fig. 2 had digitized the recorded signal, eg. read the instantaneous wave position say every ½ second we would have obtained a time series

$$a_1, a_2, a_3, a_4, \ldots, a_n$$

By using this time series we may also find the significant wave-height H_s in the following manner

$$H_s = 4\sqrt{(a_1^2 + a_2^2 + \ldots + a_n^2)/n}$$

Hence we may now recall that H_{max} was proportional to H_s or we may say that H_{max} is proportional to the rms value. (This relationship is quite useful if we in a digital computer working on line on a recorded wave-history want to estimate the most probable largest wave-height in say the next 500 wave encounters).

We have until now concentrated on the wave-heights, but a wave is also characterized by its period. In wave-theory, the wave period is also a random variable, and for a wave system we talk about its average wave period T_0 and significant wave-height H_s, where

$$T_0 = (T_1 + T_2 + T_3 + \ldots + T_N)/N$$

We may use this to estimate the average number of waves N, say in a time period t. Hence

$$N = t/T_0$$

for T_0 = 7 seconds, t = 1 hour we find

$$N = 1\ 60\ 60/7 \sim 514$$

possible wave encounters.

As for regular waves, we may also for irregular waves define a steepness. We often use the significant steepness defined as

$$s = 2\pi\ H_s/gT_0^2$$

For encountered wave systems, this value will very seldom be larger than 1/10, which is considered as a very steep wave system, occurring at an

early stage of a storm development.

We defined how we could estimate the most probable largest wave-height. In real life the actually experienced max value will, however, never be exact this value. If we in an ocean area distributed a large number of wave bouys, and during one hours period, recorded the wave history, all these recordings will give the same H_s and T_0, however, H_{max} will vary from place to place. These maxima may again be sorted in the same manner as we sorted wave-heights recorded at one location.

If we had done this we will find a general pattern, but this will not be introduced here. We will only point out that even if we estimate a maximum wave-height by the given methods, we have about a 33% chance to find a smaller maximum and a 67% chance to find one which is larger. However, it must be pointed out that the deviation from the predicted maxima will not be very great, except may be once in a life time. Such a wave, we will call a freak-wave.

2.1 Wave-spectra

Once more we return to our wave record. From this we have picked out a wave-height with a corresponding wave period. We will find as previously stated that the wave system is composed of an infinite number of individual wave-height and -period combinations. For each wave period group we may find the average wave energy ($E = 1/8\ \rho g H^2$).

We often represent the wave energy in a wave-power spectrum as shown in Fig. 4. This spectrum does often take on a special shape which again may be represented by mathematical function. One such representation which is often used Pierson-Moskowitch wave spectrum.

The wave-spectrum represents the average wave energy present in the wave system. This energy content is again proportional to the rms-value of the time history signal.

In some cases we will experience a double peaked spectrum, Fig. 5. This

indicates that the wave system encountered is composed of two basic wave systems. In such cases the wave system is a mixture of old swell and fresh wind driven seas.

The wave spectrum may also turn out to be very "sharp" ,containing only a few wave periods. This spectrum is a swell spectrum consisting of waves travelled from a wind driven wave system far away. As we may recall, waves of different wave-length travel at a different speed. Swell are waves of the same wave-length travelling with the same velocity.

2.2 Episodic Waves

Off the coast of South Africa, between Durban and Port Elisabeth mariners have encountered quite often some extremely large waves. Contrary to the freak waves introduced above which are impossible to predict, these waves which we have chosen to call episodic waves,may be predicted.

Episodic waves occur under special met eorological conditions, where local wind-driven seas are superimposed on the large swells often approaching South Africa from South West. These swells are influenced by the continental shelf, retarded and increases in height, but maintain their long wavelength (~ 1000 meter). These waves mix with the wind-driven sea which have gained energy from the fast running Aguhlas current creating steeper waves. Under such conditions there exist a fairly high probability that these two wave systems act together creating a huge wave, often 3-4 times that observed from ships. The wave will only last for a short time period, and then disappear again.

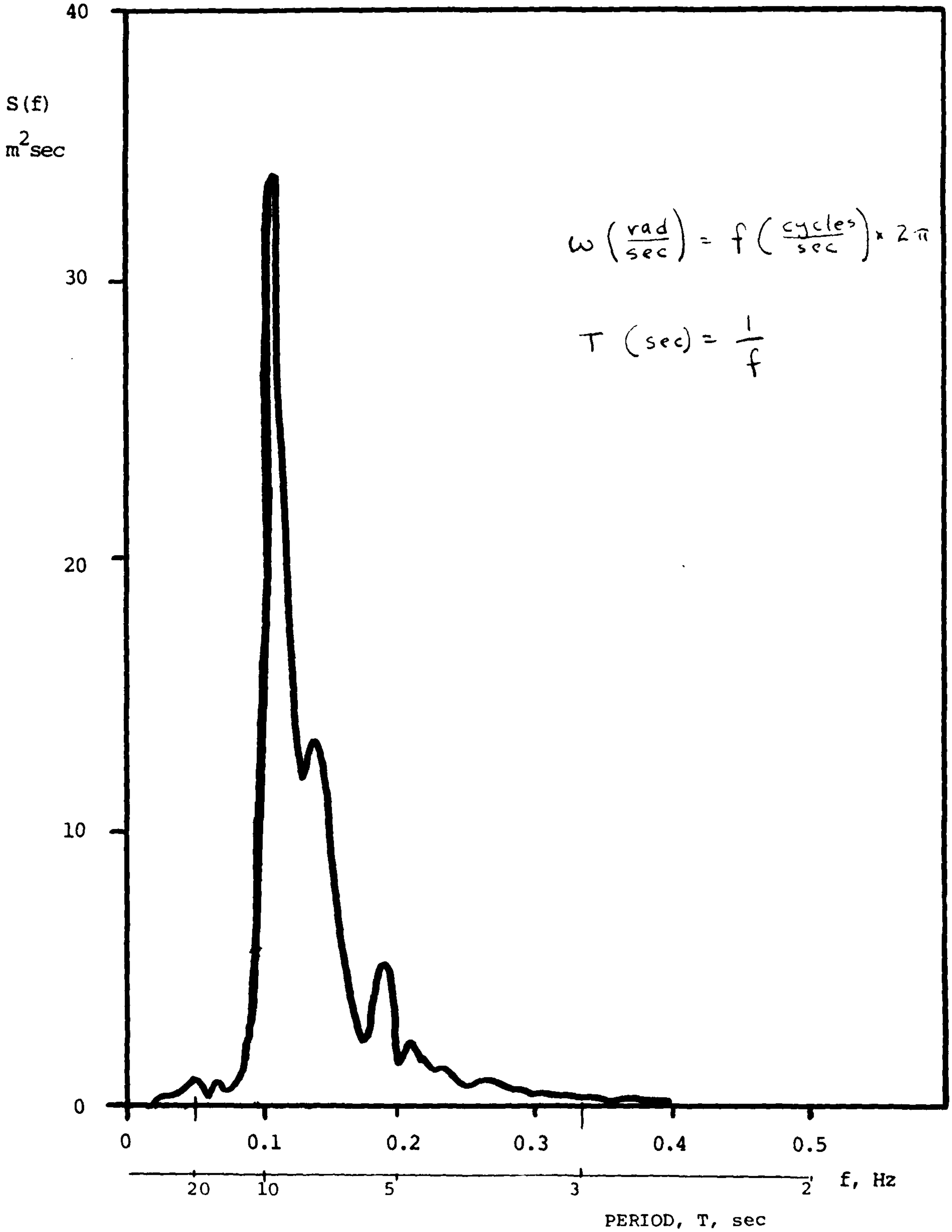


FIG. 4 Wave power spectrum

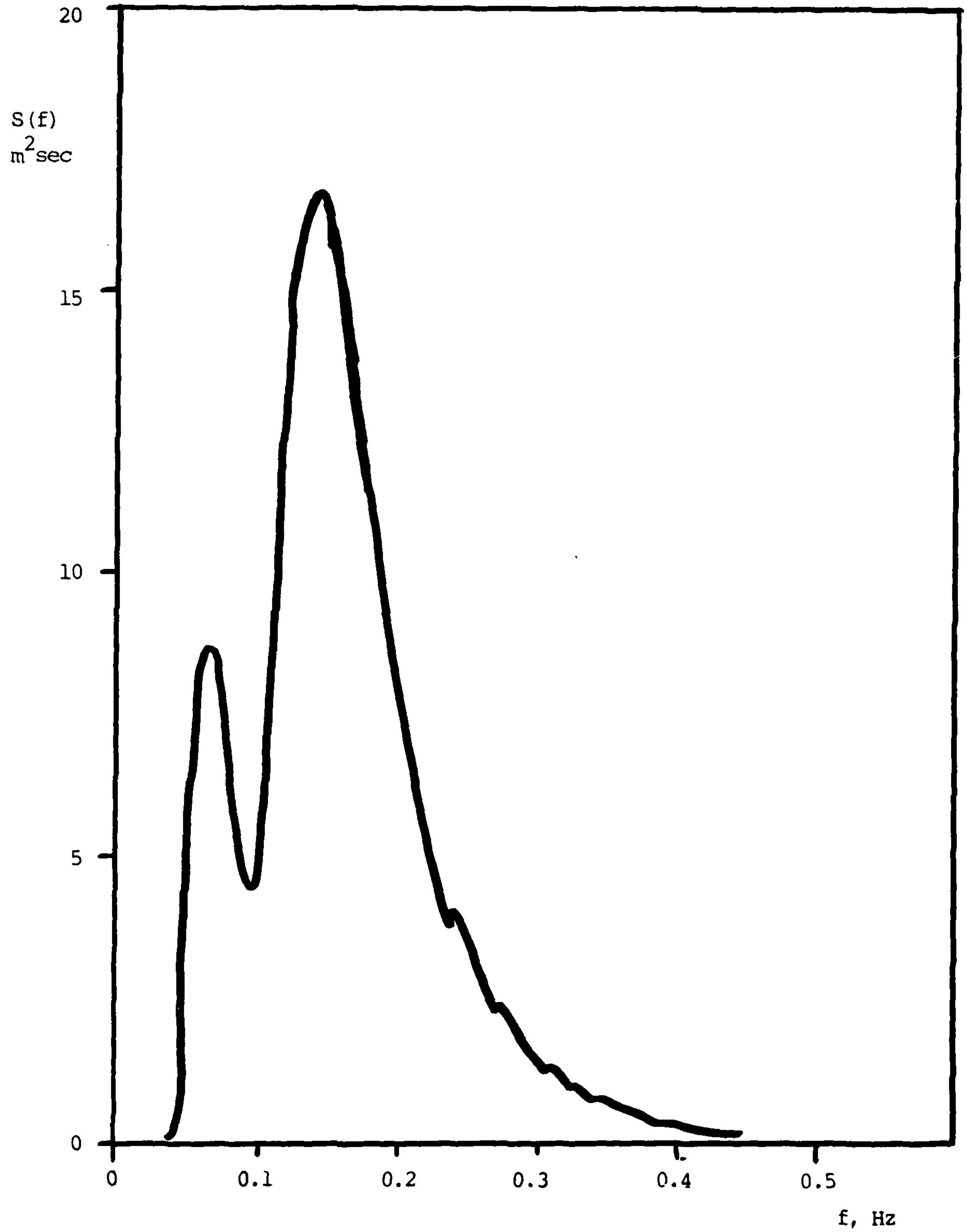


FIG. 5 Two peaked wave power spectrum

Depending on what direction one approaches the wave one will make two different observations. Coming from South one will suddenly find a big "hole" in the ocean in front of the ship, while coming from North the ship will enter into a long downhill slope, then suddenly at the end of this slope hit a "wall".

Episodic waves warning are now issued in these waters, and one may reduce the chance to meet such waves by manoeuvre out of the Aghulas current and away from the continental shelf.

3.0 Wave induced motions and loads

A ship moving in a wave system is free to move with 6 degrees of freedom, namely in roll, sway, yaw, heave, pitch and surge. When studying these motions we may approximate the ship by a mass, spring damper system. Fig. 6. The mass represents the ship itself, the damper is equivalent to radiated waves and viscous effects, and the spring represents the restoring forces (buoyancy, gz, etc.).

Such a system is termed a linear system, and when exited by a sinusoidal force at a given frequency (period) the system itself will oscillate at the same frequency. Depending on the frequency of the exiting force, the responding motions will be differently amplified. At a given frequency determined by the mass and restoring force the system may oscillate in resonance, e.g. the amplification factor is maximum. (Actually, if no damping was present, the amplitude will approach infinity). The amplification factor for different damping coefficients ζ as a function of frequency is shown in Fig. 7. The frequency scale is made non-dimensional by the resonance frequency ω_n.

For conventional ships the roll resonance frequency may be estimated by

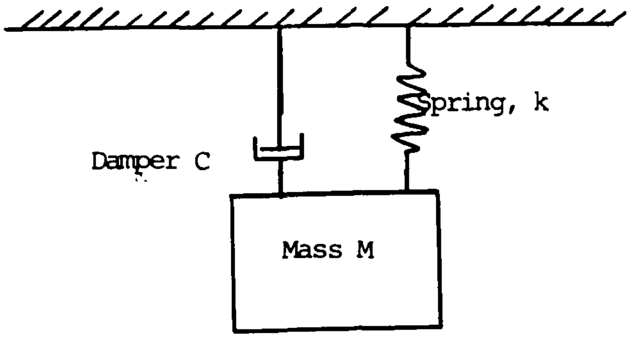


FIG. 6 Mass, Spring, Damper system

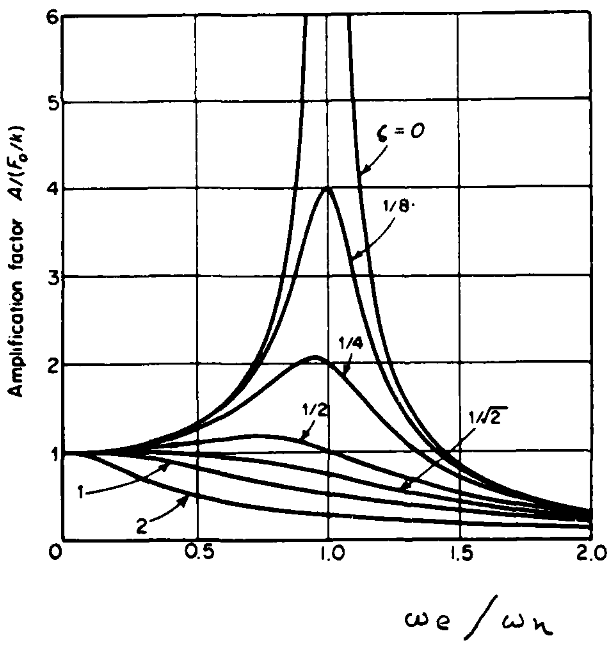


FIG. 7 Frequency response curve (RAO)

$$\omega_{ROLL} = \sqrt{g.GM}/k_{xx} \sim 3\sqrt{g.GM}/B \quad \text{(in rad/sec)}$$

or the roll period $T_{ROLL} = 2\pi \dfrac{B/3}{\sqrt{g.GM}}$ since $\omega = 2\pi/T$

For the pitch motion we may put

$$T_{pitch} = 2\pi \quad k_{yy}/\sqrt{I_w} \sim L/4 \quad \text{(in seconds)}$$

where GM - metacentric height

B - ship beam

L - ship length

k_{xx}, k_{yy} - radius of gyration

I_w - moment of water plane area

Fig. 7 is representative for the heave, pitch and roll motion. Heave and pitch motions are in general heavily damped while the roll motion is only slightly damped. To improve the roll motion damping characteristics, we introduce for instance bilge keels, flume tanks, etc.

The damping coefficients have in general the following range

Roll	$0.01 < \zeta < 0.20$
Pitch	$0.25 < \zeta < 0.60$
Heave	$0.30 < \zeta < 0.70$

The exiting frequency is usually that of the wave frequency, if the ship has no forward velocity. However, if the ship has a forward velocity, the wave-frequency as experienced by the ship will change. Hence the frequency in Fig. 7 actually represents the frequency of encounter.

The following relationship can be found for wave-frequency and frequency of encounter

$$\omega_e = \omega + \frac{\omega^2}{g} U \cos\beta \qquad \text{(in radians/sec)}$$

where U is the ship speed (in m/sec) and β is the angle between the wave system and the ship $\beta = 0°$ means head sea, $\beta = 90$ beam sea, $\beta = 180°$ following sea.

If U is in knots we may convert the speed to m/sec by

$$U[m/sec] = U[knots] \cdot 1852/3600$$
$$= 0.51\ U[knots]$$

3.1 Influence of changed speed and heading

In head seas, increase speed will give increased frequency of encounter. Keeping the speed constant, but changing the heading angle from head, to beam to following seas will reduce the frequency of encounter.

Examining Fig. 7, we may conclude the following if the wave-period is larger than or equal to the resonance period. For head seas, increased speed will increase the frequency of encounter and give reduced motions. A speed reduction will increase the motions. If the speed is kept constant, a decrease in heading angle from $\beta = 90°$ will give reduced motions while an increase in heading-angle will give increased motions until $\omega_e/\omega_n = 1$.

If $\omega_{wave} > \omega_n$ and $\beta = 0°$, a speed reduction will reduce motions, increased speed will give increased motions. Keeping the speed constant and change heading will, by starting from beam seas and head more into the waves increase motions, while turning away from the waves give reduced motions.

3.2 Influence of reballasting

By reballasting the ship, we may change the load distribution resulting in new gyradii or water-plane areas. This will change our resonance frequency and again alter the motions response.

However, in practice at sea, the roll is the only motion which we can say is effectively changed by reballasting procedures. This is the case since this motion is so slightly damped and quite sensitive to changes in GM.

3.3 Response amplitude Operator

The type of diagram presented in Fig. 7, is termed a Response Amplitude Operaor, RAO. As previously mentioned the RAO will tell us how the ship will respond (resulting ship motion) when encountering a wave at that frequency (the frequency of encounter).

Hence by combining the knowledge of the RAO's with that of the wave spectrum, we will be able to judge the ships seakeeping performance in that wavesystem. As we may recal, the wave spectrum indicates the average waveheight we should expect to encounter at a given frequency. If the maximum of the wave-spectrum is close to the same frequency as that of the resonance for the RAO, we will have a ship with poor seakeeping qualities.

If on the other side we had a ship with a resonance frequency far from that of the maximum of the wave spectrum we will have a ship with good seakeeping qualities. This is the case since ship motions hardly will be amplified for the tall waves, and since those waves that may cause significant amplification in general are very small (and therefore contain little energy)

Such characteristics are obtained for the semi-submersibles. These structures have in general a resonance period well out of range for that of encountered waves.

If we in ship design want to have a ship with good seakeeping

characteristics, we should try to arrive at a design with long resonance periods. (For heave- this could be achieved by giving the ship a small water plane area: for pitch - a large radius of gyration and a small moment of the water plane area: for roll - a large radius of gyration and a small GM. A large radius of gyration is obtained by moving the mass of the ship far away from the axis of rotation, for ships this means keep the weight in the fore and aft part of the ship and in wing-tanks etc. as far away from the centerline and water plane as possible).

3.4 Wave induced loads

A wave will in addition to toss a ship around also bend and twist the hull. Here we will not deal with these phenomena except stating that if a ship is loaded within the limits given in the load manual, the hull itself should be able to withstand the wave forces, provided ship motions are sought minimized (or reduced) in rough weather.

In order to significantly change the wave loads the ship must be exposed to large changes in hull design parameters or large changes in weight distributions.

The wave loads will in general not be as sensitive to changes in speed and heading, as that of the ships motion level.

3.5 Stability in waves

The still water stability (righting arm curve) can be substantially changed if the ship is put in a wave. The wave profile along the ship having a through midships and a crest at the bow and stern will for instance increase the ship's stability. On the other side, a wave crest amidship will reduce the ship's stability.

For certain hull forms (large forward and aft flare) one may experience a complete loss of stability when having a crest amidships.

In following seas, we can obtain a ship speed equal to that of the wave speed. Then if the ship is stationary positioned in the wave with a crest amidship, a small disturbance will cause the ship to capsize.

Another phenomenon, called parametric exitation of the roll motion will be experienced when the wave period is about ½ the roll resonance - or equal to the roll resonance - period. In this case motion energy will be transferred from heave motion to roll motion creating for certain ship types unexpected large roll angles. These roll amplitudes will be obtained within 2-4 roll cycles. For certain ships having large changes in waterplane area with draught the energy transfer will be substantial. It has been shown that ships of such design, complying with current stability requirements will capsize in moderate sea states (wave-heights 6-9 m).

However, if the ship is equipped with bilge keels, or otherwise have a fairly large amount of roll damping capsize is prevented, but still, large roll angles are encountered. This violent roll motion will be encountered in following seas, and may effectively be eliminated by changing speed or course to a frequency of encounter that is unlike that of ½ the roll resonance period.

4.0 Hull Surveillance Instruments

The wave induced ship motions and loads may be registered by sensitive instruments and analysed in digital computers. In this chapter we will shortly discuss their basic principles of operation, and point out some typical areas of application or where special thought must be given to the information provided. The concept of response monitoring is portrayed in the figure on the following page, and described in more detail in Appendix B.

4.1 Principle of operation

A hull surveillance instrument takes its main information from measured ship responses. This could be wave-induced stresses, accelerations, motions, pressures etc. Most common are accelerations and stresses.

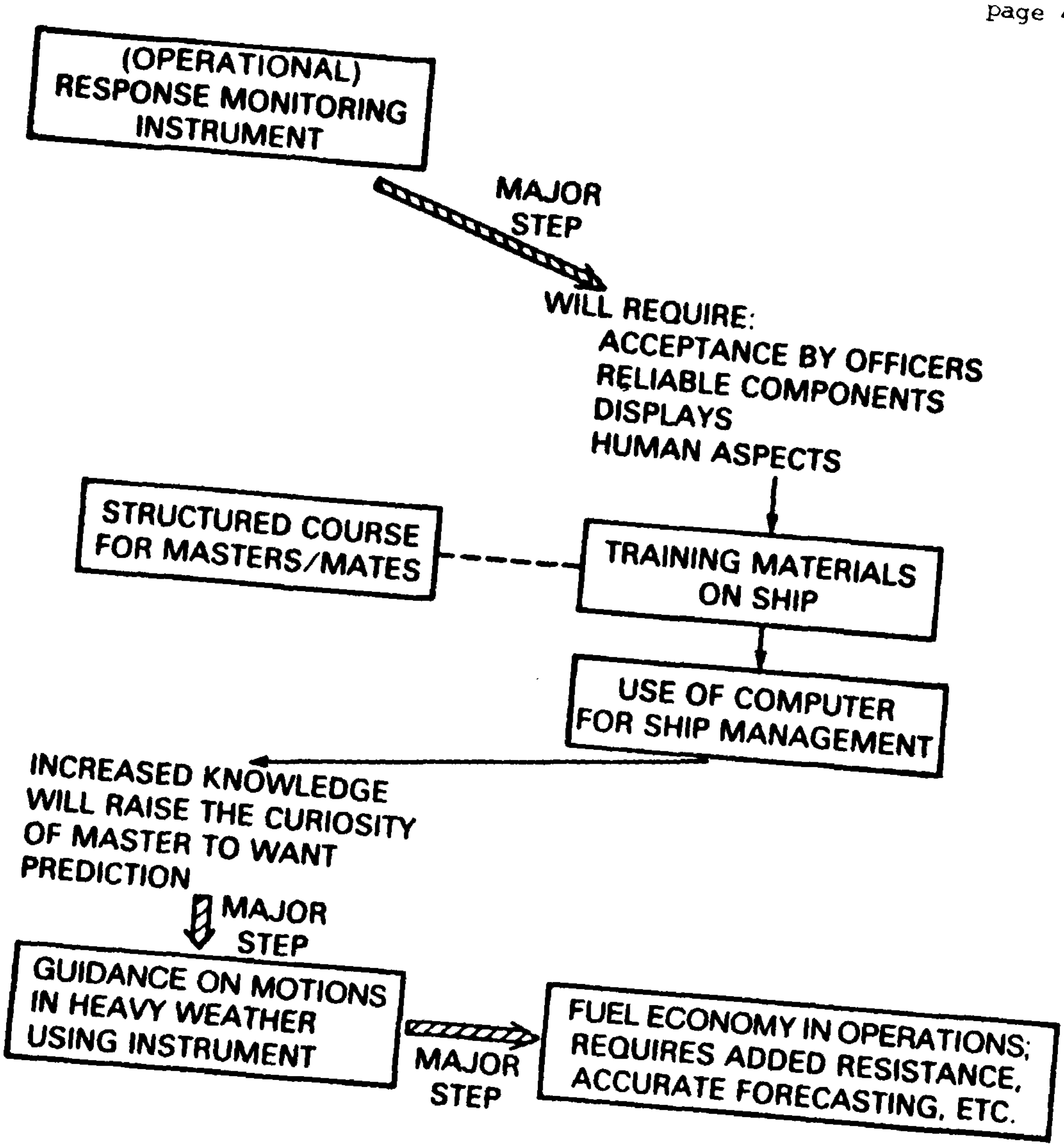
The wave induced motions and loads are as irregular as the wave surface. Hence it is found practical to treat the wave loads as we treated the wave surface itself by statistical tools. A ship is in general considered as a linear system and for such systems, the response characteristics will have the same properties as that of the wave surface.

Hence the most probable largest motion or load in a wave system will be proportional to its rms value. The rms value is computed in the same manner as that for the wave-surface. (Except that a: = (a_i* - a) where a is the signal mean value (still water bending moment for wave-induced longitudinal stresses) and a_i* is the instantaneous value (static pluss dynamic).

The rms value will when displayed to the mariner tell him what the current wave load situation is like. In principle a ship motion and load monitoring instrument.

By saving the past rms values it is possible to construct a trend in the load pattern (trend analysis).

By using the ship as a wave buoy or taking information from other sources(wave forcasts, wave rider buoys etc.) one may establish the sea state. Such iformation may be further used, knowing the ship RAO's to give predictions on what may happen when changes are made in speed, heading angle ec. (ship guidance unit). The accuracy of such predictions or guidance are, however, questionable, and is believed to be of limited value. However, they will probably be capable of telling wether or not a change in course/speed will improve or worsen the situation.



RESPONSE MONITORING AND GUIDANCE — THE CONCEPT

4.2 Practical experience

Hull monitors have been installed on a couple of dozen ships and the following examples should demonstrate their practical use.

4.2.1 Rough weather navigation

A master changed from a small ship to a larger ship. His experience from the small ship told him to take the wave 15-30° off the bow in rough weather to reduce the vertical motions. Sailing the larger ship he learned by observing the ships motion monitor that this was not always the case for this ship. In fact head seas turned out some times to be more favourable. (Wavelength shorter than ship length. Consult rough weather guidance charts).

A master learned that vertical motions sometimes were reduced by sailing at fulllspeed, head into the waves and increased when the speed was reduced. (Wave-length much shorter than the ship-length).

A ship entered a heavy storm area experiencing increased motions. By reducing speed the master limited the loads to a certain value on his motion monitoring meter. Being short of time he decided to move around the storm area in an attempt to save time. Within a short period of time while moving away from the storm the monitor told him of reductions in loads. This was not observable by human senses. But following the indications of the motion monitoring unit he was back at original course at full speed within two hours. A manoeuvre he could not have completed so successfully without the aid of the instruments.

4.2.2 Evaluate the environments

Hull monitoring units have confirmed to mariners that sailing from deep water into shallow water may result in rougher motions even though the surface wind remained unchanged. (Waves get higher when influenced by the bottom).

By changing from one ballast condition to another the motion monitor may indicate if this improves or worsens the situation. One master experienced that what he believed to be a more favourable load condition turned out to be worse.

A master experienced rather high motion levels on the ship while sailing in Beaufort 2. Later he encountered weather of Beaufort 8 with taller waves, but the same ship response level on the monitor as in the Beaufort 2 case. In principle taller waves will give larger motions. However, in this case the taller waves had a substantially shorter wave-length than the Beaufort 2 waves. The small Beaufort 2 waves hit the ship almost at resonance causing large motion amplifications. The taller Beaufort 8 waves caused less amplification since the wave period was shorter in this case causing the same motion level in both cases.

In conditions with poor visibility on large supertankers it is impossible to have a feel of the ship. Hull monitoring equipment have been used to confirm the general condition of the sea on such ships at night etc.

By watching the trend in recorded motion levels one mate noticed a substantial increase when sailing into the area between Port Elisabeth and Durban. Nothing could be observed on the sea. Later it was learned that the ship sailed into an episodic wave condition area. The instruments had registered that something unusual or unobservable was going on. Action could have been taken to avoid the area.

4.2.3 Pitfalls

The motion monitors works on a statistical basis requiering a certain minimum of information before a "statement" could be made. Hence one must allow for sometime before the effect of a speed reduction or course change could be read from the instruments. (Usually 3-5 minutes must be allowed for).

Since we work on a statistical material, certain noise pulses, as for instance created by the radio transmitter engine room noise etc., will give an unwanted large single recorded response amplitude. Such a signal dropout may for a short

time period give a false motion response level, however, the readings will be restored to normal within 3-5 minutes in such cases.

For strain gauges thermal effects as for instance caused by green seas may cause sudden large artificial dynamic response pulses creating a dramatic rise in recorded response level for a short time period. Such signal dropout should be of no concern to the user since the meters will return to their natural value within minutes.

Gauges mounted to detect longitudinal wave-induced stresses at port and starboard side will to someone unexpectedly indicate higher stresses on the leeward side than on the windward side. However, such conditions are quite normal and just indicates the true nature of the loads experienced by the ship.

5.0 Ship Handling in rough Weather

For more details, reference is made to Det norske Veritas Report No. 81-0215 included as an appendix to this report.

Here we will only limit the discussion to point out the importance of evaluating how the wave-length is related to the ship-length before measures are taken to reduce the wave loads.

In principle we distinguish between 3 groups

a) Wave-lengths equal to the ship-length
b) Wave-lengths equal to about half the ship-length
c) Wave-lengths equalto about one quarter of the ship-length

For case a, speed reduction and falling off from the waves usually gives the best result.

For case b, speed reduction and falling off 20-40° does not always give much change in conditions. Large changes must be done in order to see significant improvements.

For case c, increased speed and head into the waves will usually give the best results.

VIII LIST OF REFERENCES

More details on the individual subjects may be found in the following basic text books:

/1/ Principles of Naval Architecture. Edited by John P. Comstock. The Society of Naval Architectures and Marine Engineers 1968.

/2/ Basic Ship Theory, K.J. Rawson and E.C. Tupper: Longmans, Green and Co. Ltd. 1968.

/3/ Dynamics of Marine Vehicles. R. Bhattacharyya, New York N.Y. John Wiley & Sons. 1978.

/4/ Marine Hydrodynamics. J.N. Newman: The MIT Press. Cambridge Massachusetts 1977.

/5/ Human Error? D. Todd Jones, Proceedings of the Marine Safety Council, April 1982.

/6/ Help for the Human - its Instrumental, H.P. Cojeen and E.A. Chazal, Proceedings of the Marine Safety Council, April 1982.

/7/ How a Hull Takes Stress, Proceedings of the Marine Safety Council, November 1981.

APPENDIX A

VERITAS Report No. 81-0215:

"AN INTRODUCTION TO SHIP HANDLING IN ROUGH WEATHER"

by S. Robertsson and K. Lindemann

Det norske Veritas
Research Division

POSTAL ADDRESS: P.O.BOX 300, 1322 HØVIK, NORWAY
TELEPHONE: +47(02) 12 99 55
CABLE ADDRESS: VERITAS, OSLO
TELEX: 16 192 VERIT N

TECHNICAL REPORT

VERITAS Report No. 81-0215	Subject Group	Date 17. March 1981	
		Department 54	Project No. 54 30 00
Title of Report: AN INTRODUCTION TO SHIP HANDLING IN ROUGH WEATHER		Approved by: Kåre Lindemann, Kåre Lindemann, Principal Res. Eng.	
Client/Sponsor of project: SO3-PROSJEKTET		Client/Sponsor ref.	
Work carried out by: S. Robertsson, K. Lindemann		Reporters sign.: K. Lindemann	

Summary

Ship handling in rough weather is a difficult task where general guidelines cannot be given. However, some basic principles as to what will happen in a generalized situation may be worked out. This is the intension of this report whose use is aimed at ship navigators and as a teaching aid in the naval academies.

4 Indexing terms

SEAKEEPING
SHIP HANDLING
GUIDANCE
EDUCATION

Distribution statement:

- [ ] No distribution without permission from the responsible department.
- [ ] Limited distribution within Det norske Veritas.

WHAT IS SO3

The SO3-project is an interdisciplinary and interinstitutional research project sponsored by NTNF (Norges Teknisk-Naturvidenskapelige Forskningsråd), The Norwegian Maritime Directorate, Det norske VERITAS, Norcontrol, The U.S. Coast Guard and participating ship owners. The project is steered from a steering committee composed of representatives from the marine environment.

Det norske VERITAS is responsible for the project management.

The aim of the SO3-project is to improve safety for the crew, ship, cargo and environment when sailing in rough weather. The following main tasks are undertaken in order to achieve this goal.

a) Develope and test in full scale methods (global and local surveillance, trendanalysis, prediction unit, tour recorder, roll analyzer) which will be a part of a 2nd generation weather damage reduction system.

b) Improve the navigators ability to evaluate the influence of the environment on the hull, and thus put him in a position to handle the ship more effectively and reduce the likelyhood of damage.

c) Prepare knowledge of ships seakeeping capabilities for improved education of ship navigators (textbook also intended for self studies).

The project will include systematic analysis of ships seakeeping capabilities, basic research on ships roll motion, modell-tests, full scale experiments, preparation of methods suitable for instrumentation and present knowledge of a general character on ship handling in rough weather.

LIST OF CONTENTS PAGE

INTRODUCTION

Scantling requirements presuppose that ships are competently handled in rough weather. However, no classification society has explicitely defined what they mean by competent handling. This is the case since guidelines are hard to give, taking into account all possible situations encountered at sea.

The ultimate responsibility for the ship is in the hands of the ship captain. It is therefore in the public interest that he is given the best possible opportunity to fulfil this task.

In the past, ship navigators gained experience in ship handling in rough weather at sea. Before entering a commanding position, the ship navigator had several years of experience at sea on ships which had similar seakeeping qualities. In this process he learned how a ship should be handled in rough weather and consequently prudent seamanship. The last decades have seen the development of a wide variety of ship types, such as the ULCC, VLCC, LNG and LPG carriers, LASH ships, and fast container ships, which have different seakeeping qualities and require individual handling in rough weather. Consequently, not all of the ship handling experience gained onboard one ship type is applicable on another ship type, and hence the navigator's ability to optimize the ship handling in rough weather is often inadequate.

Weather forecasts have become more reliable, cover larger areas and can be received on most ships. As a consequence ships are routed to avoid the worst storms and the navigators obtain less experience from rough weather passages.

Social conditions on board ships are changing, navigators have working conditions where they are down to 50% of the year at sea and when at sea do not always return to the same ship. The consequence is obvious, less experience with rough weather conditions, and the experience gained cannot necessarily be taken

from one ship to another.

Naval education does not provide the student with thorough knowledge on how ship design, loading, speed reduction and change in course will influence the seakeeping qualities. Navigators of today have less practical experience and are required to operate capital intensive units on tight schedules in order to give a sufficient payoff on the invested capital. In this situation the navigator is required to handle the ship competently without really knowing what is meant by the expression.

In view of the above, the SO3-project has taken action to better the possibilities for the navigator to handle a ship in a more efficient and confident manner. As a part of this work the following guide to ship handling in rough weather has been worked out.

It is important to notice that the given guidelines, if followed, will not secure the ship in all possible encountered rough weather situations. For that the ocean environment is too random in nature and cannot possibly be fully described. However, it is believed that the introduction given herein to manoeuvering of ships in heavy weather will form a fundamental basis for the general understanding on how different wave systems influence the ships seakeeping qualities.

IRREGULAR WAVES

The irregular appearance of the sea surface may be regarded as the sum of a large number of regular wave trains with different amplitudes, wave lengths, and direction of propagation, Fig. 1. The characteristics of the irregular sea surface depend on the distribution of amplitudes, wave lengths, and directions among the individual wave components, and an infinite number of combinations are possible. The wind is the generating force behind

the visible open water waves and several factors are affecting the resulting wave system, such as:

- wind velocity
- duration, the length of time the wind has been blowing over the water surface
- fetch, the stretch of water from land the wind has affected
- currents, steady sea currents and currents produced by tidal variations
- sea floor configuration, the water depth has effect on the wave system

In the vincinity of a storm centre where the wind has been blowing at varying strength and direction for some time, the sea is built up by a large number of wave components travelling in different directions. This is often called "confused" sea.

At a distance away from the storm, or after the wind has ceased to blow, the wave components with a short wave length die out. Left are the long wave components which travel long distances. They form the swell which is more regular in appearance and almost unidirectional.

Regardless of the type of sea, whether confused sea or swell, two parameters are often used to describe the wave system; the significant wave height $H_{1/3}$, and the mean wave period $\bar{T}$.

The significant wave height $H_{1/3}$ is defined as the mean height (crest to trough) of the waves which are larger than 2/3 of all the waves in the wave system. $H_{1/3}$ is often regarded as being close to the wave height a trained observer will visually estimate.
The mean wave period $\bar{T}$, is the mean time between the wave surface's crossing of the still water level from below.
The mean wave period $\bar{T}$ is usually difficult to correctly estimate visually, but the timing of the cyclic motion of a small floating

object may give a good estimate.

MANOEUVERING OF SHIPS IN HEAVY WEATHER

A ship travelling in a seaway responds to the exciting forces from the waves by means of translational motions in three directions, heave, sway, and surge and rotational motions about three axes, roll, pitch, and yaw. Fig. 2. The hull girder is also subjected to wave induced bending moments and torsional moments.

In severe cases when the relative motion between the wave surface and the ship is large, shipping of water on deck and slamming may occur. The wave pattern in a confused sea is completely irregular, in the sense that a particular sequence of troughs and crests is never repeated. The ship's response will also be of an irregular nature. Fig. 3. It is therefore often convenient to use various mean values when describing waves or ship responses. Such values may be the mean of all values, or the mean of the largest one tenth of all values, or any other mean. A value which is commonly used is the mean of the highest on third of all maxima experienced during a certain time, and it is usually referred to as the "significant value", x_s.

The significant value will be used in the following descriptions of ship responses, and it is important to bear in mind that it is a statistical value and that smaller and larger maxima will occur as well. If, for example, a ship is pitching 500 times during one hour, a histogram of the pitch angle maxima may be as illustrated in Fig. 4. The histogram may often be well approximated by the Rayleigh probability density function:

$$f(Z) = 4Ze^{-2Z^2}$$

where $Z = x/x_s$

x = a maximum

and x_s = the significant value, single amplitude

The largest of these 500 maxima may be estimated from

$$X_{max} = X_s\sqrt{\tfrac{1}{2}\ln 500} = 1.76\ X_s$$

This is, however, only an approximation as may be illustrated by the following example:

Let 100 identical ships be travelling with the same speed, course and loading condition in the same wave system for one hour. They will all have a significant pitch angle equal to X_s. During this time most of the ships will experience a largest pitch angle close to 1.76 X_s, but some will experience a smaller value (the lucky ships) and some a larger value (the unlucky ships). This is illustrated in Fig. 5 and the Table below

Response range X/X_s	Number of ships with largest value in the range	
1.4 - 1.5	1	lucky ships
1.5 - 1.6	4	
1.6 - 1.7	16	
1.7 - 1.8	26	← estimated largest value X/X_s = 1.76
1.8 - 1.9	23	unlucky ships
1.9 - 2.0	15	
2.0 - 2.1	8	
2.1 - 2.2	4	
2.2 - 2.3	2	
2.3 - 2.4	1	

TABLE 1

As can be seen from the table the range X/X_s = 1.7 - 1.8 contains the largest number of ships, but 53 ships, or more than 50% of all ships, will in fact experience a maximum larger than X/X_s = 1.8. As a rule of thumb we may therefore use $X_{max} \approx 2X_s$ as a conservative estimate of the largest value which may be encountered.

When operating a ship in heavy weather, it is often desirable to reduce some of the ship's responses in order to ensure the safety of the ship, its crew and cargo. Possible ways of doing this are changes of speed and heading relative to the waves, and sometimes a change of ballast in order to alter the draught of the vessel. By a change of ballast condition, the navigator is also affecting the metacentric height GM and by this the ship's rolling performance. Such actions have usually been carried out intuitively or based on the navigators experience.

In recent years, there has been an increasing interest in guidance systems which would assist the captain in his operation of the ship. It would for example be of value to know the relative merits of various actions before they are carried out, rather than having to rely on trial and error procedures. Then, for example, in a situation when the shipping of water over the bow is excessive due to the large relative motions, the captain would from a guidance chart be able to compare and evaluate the effects of a change in course or speed prior to his decision. He may for example find that a small change of course would be more favourable than a reduction of speed.

There are of course other factors the navigator must consider before he finally makes his decision about what actions to take. His ability to manoeuvre may for example be limited due to other traffic or by operating in restricted waters. He must also decide which responses are of prime importance for the particular ship he is sailing. For a tanker he may, for example, be prepared to accept an increase of the roll in order to reduce the amount of water being shipped over the bow. On a general cargo carrier on the other hand, an increase of the roll and associated transverse accelerations may be too hazardous for the cargo.

Finally, the extra time and cost incurred by the different actions may be considered. The extra time needed for a journey

between two points with reduced speed or with altered course may be compared and evaluated from a figure such as Fig. 6, whereas the extra cost is dependent on the relative importance of speed on the total operational cost per hour.

FA 'RS AFFECTING A SHIP'S RESPONSES

A ship's behaviour in a seaway depends on the size and shape of the ship and the type of wave system in which it is sailing. The factors may be summarized in the following way:

The environment:

- The significant wave height of the wave system. This is the average of the highest one third of the waves and most responses are proportional to the significant wave height. (About the same as the visually observed wave height).
- The mean wave period. (About the same as the visually observed wave period). A measure of the wave lengths of the components present in the wave system, where long waves have the longer periods. The ship is more responsive to some wave lengths than others.
- The directional energy spread. A small spread means that most wave components travel in approximately the same direction. A large spread means that various wave components travel in different directions which may be the case when for example recent wind waves are generated in a direction different to that of old swell from a previous storm. The amount of spread affects the ship's response from course alterations.
- Wind and current speed and direction. Apart from having the effect of generating waves, wind and current may sometimes have an effect on the ship's motions. In the following discussion only the motions and loads induced by the waves will be considered, and the effect of the wind and current will be excluded.

The ship:

- The ship's size. A large ship may be relatively uneffected by a sea which causes large motions on a small ship. The opposite can also be the case when for example very long swell may induce large bending moments in a large ship whereas a small ship is less affected by such long waves, Fig.7.
- The form of the ship. Factors such as the block coefficient, the length to breadth ratio, the length to depth ratio, the shape of the bow, the amount of bow flare, etc. all have minor effects on the ship's behaviour in a seaway.
- The loading condition. Mainly affecting the metacentric height and thereby the roll motion amplitude and period. Loading may also have some effect on other motions and bending moments. The draught and trim is of importance for the probabilities of experiencing slamming or shipping water over the deck.
- The ship's speed. This affects the frequency of encounter with the waves and hence the excitation period from the waves, which is of importance to most responses.
- The heading relative to the waves. The direction of the waves relative to the ship is of great importance to most responses. By a change in course the frequency of encounter and the nature of the exciting forces (i.e. the sequence of how the waves hit the ship) are changed and hence also the responses, which may be reduced or increased.

From this summary it may be concluded that for a particular ship in a particular sea condition, the navigator can affect the ship's behaviour mainly by altering the ship's speed and course and to some extent the ballast condition.

GUIDELINES FOR SHIP HANDLING IN ROUGH WEATHER

In the previous section it was mentioned that a ship's responses are approximately proportional to the significant wave height, but also a function of the mean wave period. This can be illustrated

by the response of pitch motion in Fig. 8. Each curve in the figure represents the significant pitch amplitude per meter significant wave height as a function of the mean wave period for a particular speed and direction.

It should be noted that Fig. 8 is valid for a range of ships with different lengths, provided their hulls are of the same shape. This has been accomplished by putting the mean wave period along the abscissa in a non-dimensional form. To obtain the wave period the values should thus be divided by $\sqrt{g/L}$ where g is the acceleration of gravity and L is the length of the ship. The non-dimensional approach has been found convenient when describing ship responses, as ships of different sizes can be represented in one figure. In Fig. 9 the range of wave periods in seconds are shown as a function of ship length, and it can be seen that a wave period of say 8 seconds would be interpreted as "long" for a ship with a length of 100 m, whereas it would be regarded as "short" for a ship with length 400 m.

In general we may say that the ship experiences long wave periods when the wave-length is about equal to the ship length. When the wave length is equal to about ½L (half the ship length) the wave periods are of the medium type. For waves in the order of 1/4L (a quarter of the ship length) the waves are of the short type.

Guidance charts

It is not possible within the scoop of this text to give a detailed description of how speed and course may influence all of the wave induced motions and loads on all types of ships, and the examples presented here are representing the laden condition for a VLCC with a length of 330 metres.

In order to obtain significant changes of the ship's seakeeping qualities, however, the hull shape must undergo large alterations

and the graphs may therefore give some indications on the response of other ship types as well.

The responses, which are believed to be of most importance to the safety of the ship and cargo and presented in the guidance charts, figures 10-25, are:

- the roll motion
- the vertical acceleration of the bow
- the relative motion of the bow
- the vertical bending moment midships

The relative motion at the bow, which is the combination of the bow's vertical motion due to heaving and pitching, and the elevation of the wave surface is of critical importance to control the probability of shipping green water and experience slamming.

Other responses such as heave, pitch, lateral acceleration, shear forces, etc. could also have been included, but can to a certain extent be regarded as represented by one or more of the plotted responses. For example, by reducing the vertical bending moment the shear forces are likely to be reduced and the magnitudes of pitch and heave are reflected by the vertical acceleration at the forward prependicular.

It can be seen from figure 8 that the effect of a speed or course alteration is dependent on the actual mean wave period in the wave system. A handling manual which would describe the relative effect of course and speed on a response for any wave period would obviously be too extensive to be practical. It has also been found difficult to make an accurate estimation of the actual mean wave period from a moving ship which would make the selection of the right chart difficult. A more practical approach, which will be applied here, is to divide the range of wave periods into three areas representing short, medium and long

wave periods respectively, as indicated in Fig. 8 and produce one set of guidance chart representing each range of wave periods.

The charts are produced with the assumption that the sea is "fully developed" which means that the wind has been blowing a sufficiently long time and over a sufficiently long distance such that all wave components in the wave system have been developed. Also, a standard form of directional spread is used, which means that all wave components are assumed to have a certain portion of energy approaching the ship from different directions relative to a common main wave direction. Such idealized conditions do of course not always exist in reality and the graphs should therefore be taken as indications of what the effect of various manoeuvres may be rather than absolute true values. The more the wave conditions diverge from a "typically confused storm sea" such as regular longcrested swell, or mixed wave systems (sea and swell) the less accuracy may be expected from the graphs.

How to use the guidance charts

In order to select the correct group of charts representing short, medium, and long waves respectively, Fig. 10, may be used. For the use of Fig. 10 the following information is needed:

- The relative direction β of the waves.
  For head to beam sea use the uppermost graph, and for quartering to following sea use the graph below.
- The average pitch period in seconds.
  May be obtained from the timing of ten consecutive pitch cycles.
- The ship's speed in knots.

When the correct graph in Fig. 10 has been selected from the observed wave direction, the set of guidance charts to use is

determined from the pitch period and the ship speed in the following way:

- A horizontal line is drawn from the vertical axis corresponding to the measured pitch period.
- A vertical line is drawn from the horizontal axis corresponding to the actual ship speed.
- The location of the intersection of the two lines determines the group of guidance charts to be used. If the intersection is located below the lowermost line, i.e. in the area marked (1), the ship is travelling in short waves and group 1 of the guidance charts, figures 17-20, should be used, and so on.

In each guidance chart, see for example Fig. 12, the relative effect of speed and course on the actual response is shown. On the horizontal axis is marked from 0 to 100. In the figure, the largest response value for any combination of speed and heading is set to 100 and the values for other speeds and headings are given as percentages of this. Thus, the most unfavourable heading and speed for the actual response can immediately be identified.
Below the graphs, except for the graph describing roll, the response value per metre significant wave height corresponding to 100 on the vertical axis is given. This value should, however, be regarded with scepsis, as it is valid only for the "fully developed" sea. If the actual wave system is different from this type of sea, the response value corresponding to 100 will be different to the one given, but the relative effect of speed and heading alterations may still be valid.

<u>Example</u>:

A tanker is heading into an area of bad weather. The sea which is coming from about 30^{o} off the bow is building up and heavy spray is shipped over the bow at times. The speed is 15 knots

and the roll is moderate. As the weather seems to be getting worse the captain considers a speed reduction in order avoid the risk of shipping water over the bow which may cause damage to the deck fittings. He decides to consult his guidance charts in order to verify the merits of his intended speed reduction.

He times ten pitch cycles and finds the average pitch period to be 9.5 seconds. As the heading is about 30^{o} he uses the uppermost graph of Fig.10. With the speed being 15 knots and the pitch period 9.5 seconds he finds that guidance charts 1, figures 12-15, should be used.

He them finds from Fig. 14 that the relative motion at the bow would rather increase than decrease if the speed was reduced further. Also, a speed reduction would not have a positive effect on the roll, Fig. 12, which is contributing to the wetness of the bow. He therefore decides to stay on the course and maintain the speed.

The situation is, however, getting worse. The speed has dropped to 13 knots due to added resistance from the wind and the waves. Occasionally green sea is shipped over the bow and the captain, conserned about the wave loads on the deck fittings, now considers a speed reduction to zero and a change of the heading to beam or quartering sea according to Fig. 14.

As the sea has built up more he first makes another check on the pitch period. This has now increased to 11.8 seconds, and with the speed at 13 knots he realizes from Fig. 10 that the wave system has developed towards longer waves and that guidance charts 2, figures 17-20, should now be used.

From Fig. 19 he finds that in the present wave system a speed reduction is indeed favourable, and he decides to reduce speed to dead slow ahead. Also, by changing the heading to head sea he reduces the roll as much as possible and hence minimizes the

risk for shipping water over the ship's side.

CHOICE OF MANOEUVRE STRATEGY IN ROUGH WEATHER

It is believed that guidance charts of the type previously described can be of value for the navigator when he wishes to reduce various responses in rough weather.

It is of course possible to produce similar charts for particular ships which would be of greater value for use on board.

Responses of particular interest to a specific ship could be emphasized by including more speeds and wave conditions. Different charts for various loading conditions might also be desirable. Due to the many factors involved in the choice of manoeuvres such as actual speed, heading, wave condition, type of ship, etc. it is not possible to state an overall strategy which is applicable to all ships in all situations. This can be exemplified by Table 2 where the relative merits of course and speed alterations are given for two groups of ships with block coefficients less than and larger than 0.67 respectively. The values are only approximate and obtained from the following limiting assumptions:

- The ship is sailing into rough head sea. Consultancy of Fig. 6 shows that a reduction of speed to half speed or a change of course to a heading of 60^{o} with maintained full speed will give the same time loss over a given distance. The relative merits of these two actions are found from guidance charts for the different wave periods and block coefficients and listed in Table 2.

The table serves to emphasize the importance of the mean wave period for the outcome of the manoeuvres. Different results would obviously have been obtained had the initial conditions been different such as beam sea being the original heading.

The type of ship and cargo carried may well be the decisive factors for the choice of strategy as the relative importance of various responses may differ considerably from ship to ship.

Some tentative values of the priorities which may be given various responses by some different ship types are suggested in Table 3 where each ship should be considered separately. I.e. the value 3 for shipping of water for a tanker should be interpreted as being of greater importance than slamming, and not as being more important to a tanker than for example to a bulk carrier.
The values in Table 3 are based on the following arguments:

The discomfort and possible dangers to the crew due to large roll angles, motions and accelerations will be excluded from these arguments and only the hazards to the ship and its cargo will be considered.

Tankers.

- Roll. Little importance.
  Well defined loading conditions with good stability range.
  Free surface effects small with full tanks.
  Cargo insensitive to roll.
- Motions and accelerations. Little importance.
  Some damages due to sloshing have been reported but are generally rare events.
- Shipping of water. Significant importance. A considerable part of damages in rough weather are reportedly caused to the superstructure including the forecastle by shipping of water on deck. The relative small freeboard when fully laden is the main reason for this.
- Slamming. Some importance. Small draught in some ballast conditions increases the risks for slamming, but the possibility of increasing the draught by increasing the ballast have led to few slamming damages. The introduction of

segregated ballast tanks have limited this possibility so that slamming damages may be experienced more often in ballast.

- Vertical bending moment. Some importance. Although scantling requirements make fatal damages due to large bending moments unlikely, keeping the wave bending moments down minimizes the risks for fatigue cracks developing.
- Torsional moment. Little importance. The closed cell systems formed by the hull and bulkheads give a high resistance to torsion.

Bulk carriers, including OBO and OO.

- Roll. Little importance.
  In severe cases some shifting of cargo may occur, but generally the stability is well controlled.
- Motions and accelerations. Some importance.
  Damages to tanks, holds, and bulkheads due to sloshing have been reported, and the complex structure is comparatively sensitive to cracks developing.
- Shipping of water and slamming. Some importance.
  Damages to the superstructure deck and hatches due to shipping of water have been reported as well as bottom impact damages.
- Vertical bending moment. Some importance.
  See "Tankers".
- Torsional moment. Some importance.
  The structures resistance to torsion is generally good but very large hatch openings on some bulk carriers increase the risks of stress concentrations.

General cargo carriers.

- Roll, motions and accelerations. Some importance.
  Cargo displacements causing loss of stability in rough weather have been reported.

- Shipping of water and slamming. Significant importance. A significant part of rough weather damages are caused by these events. Superstructures, deck hatches and bottom are at risk.
- Vertical and torsional moments. Some importance. The size and shape of hatch openings affects the tendencies to stress concentrations, but fatal damages due to large moments are unlikely.

Ro-Ro ships.

- Roll, motions and accelerations. Significant importance. The wide variety of cargo shipped put great demand on secure fastening of the cargo. Large forces on the lashings may be experienced.
- Shipping of water. Some importance. The large bow flare common on many ships of this type reduces the deck wetness, but instants where deck containers have been washed over board have been reported.
- Slamming. Significant importance. The generally high speed of operation and the large bow flare make them receptive to high impact pressures on the bow.
- Vertical bending moment. Some importance. Even though the construction is not very sensitive to vertical bending moments large magnitudes may be experienced when the large bow flare enters the water.
- Torsional moment. Little importance. The construction is not very sensitive to torsional moments.

Container carriers.

- Roll, motions and accelerations. Some importance. Violent motions causes large forces on the lashings for containers on deck.

- Shipping of water. Some importance.
  See "Ro-Ro" ships.
- Slamming. Significant importance.
  See "Ro-Ro" ships.
- Vertical bending moment. Significant importance.
  Large magnitudes of bending moments are introduced when the large bow flare enters the water. However, a hull girder failure is unlikely.
- Torsional moment. Significantly importance.
  The constructions with very large deck openings make the resistance to torsion low.

Other types of ships may be subject to similar discussions, such as passenger ships where the comfort of the passengers give motion responses high priorities and liquified gas carriers where sloshing impacts are of importance.

It is hoped that this discussion has served to describe some of the considerations decisive for the strategy of manoeuvering various ships in rough seas.

THE SIGNIFICANCE OF WAVE INDUCED LONGITUDINAL STRESSES

A material will fail when exposed to loads which induce excessive stresses. It seems obvious that the ship should be handled in such a manner that high stresses or large wave-induced bending moments are avoided. This is a fact that none will dispute. However, as we will see in the following, a concern for the longitudinal stress level during heavy weather encounters is of less practical value. This is the case since building codes requires the ship to have sufficient longitudinal strength to withstand the most severe weather treatment. (Local damage due to slams or green water will most probably have occured before the hull girder fails).

If we examine scantling requirements, we find that the ship is permitted to operative with a working dynamic (wave-induced) stress level of up to $f_1 \cdot 70$ N/mm^2. Occasional peak loads may be permitted to reach $f_1 \cdot 120$ N/mm^2. Here f_1 is a material factor ranging from 1.00 to 1.40 depending on the steel quality used. (These values apply to the Rules of Det norske Veritas, but equal values may be found in the rules of other classification societies). When issuing these rules due regards have been given to the different modes of failure, (brittle fracture, ductile yielding, buckling and fatigue).

In order to study the significance of the rules, full scale measurements of wave induced longitudinal stresses have been carried out. Results from the analysis of about 25.000 such registrations carried out on 14 ships covering a time period of up to 5 years of operation on a single ship is shown in Table 4. The largest ever measured stresses for the individual ships are presented in Column B. None of these recordings have exceeded the permissible working stress level $f_1 \cdot 70$ N/mm^2

In column C the project life time value is shown. For all ships except No. 6 this value will not exceed the permitted peak load

of $f_1 \cdot 120\ N/mm^2$ (120-170 N/mm^2 pending on the steel quality).

For ship No. 6 it should be expected that during the ship's life time of 20 years the stresses will exceed the permitted peak load level. However, the probability for this to occur is small. In practice this means that on the average the ship will experience one exceedance of the permitted level every second year. This might be considered inadequate, but considering that the limiting value as well as the analysis are conservative, i.e. the estimated values are probably too high, an exceedance is unlikely to result in failure.

However, as noted none of these ships have experienced excessive stress levels, and in general, when motions are reduced, so will be the case for the wave-induced stresses. Hence, it is postulated that wave-induced stresses are of less practical importance for ship handling in rough weather provided ship motions and local loads (green water and slams) are sought minimized. This apply to conventional well maintained ships. Somewhat more thought should be given to the hull girder stresses on specialized ships of a more unconventional design (large hatch openings, LNG and LPG carriers etc.).

EXAMPLE OF THE RELATIVE SENSITY OF SOME
RESPONSES TO CHANGES OF SPEED AND COURSE

SPEED REDUCTION: FROM FULL SPEED TO HALF IN HEAD SEA
COURSE ALTERATION: FROM HEAD TO 60° AT FULL SPEED

		$C_B \leqslant 0.67$			$C_B > 0.67$		
		WAVE PERIODS			WAVE PERIODS		
RESPONSE		SHORT	MEDIUM	LONG	SHORT	MEDIUM	LONG
ROLL	SPEED	-1	-1	-1	-1	-1	-1
	COURSE	-3	-3	-3	-2	-3	-3
VERTICAL ACC.AT F.P.	SPEED	+2	+3	+3	0	+2	+3
	COURSE	-1	+2	+3	-2	+1	+2
RELATIVE MOTION	SPEED	+2	+2	+3	-1	+1	+2
	COURSE	-1	+2	+3	0	+2	+3
VERT.BEND MOMENT	SPEED	+1	+2	+3	-1	0	+1
	COURSE	0	+1	+2	-1	+2	+3
TORSIONAL MOMENT	SPEED	-1	-1	-1	-2	-1	-1
	COURSE	-3	-3	-3	-3	-3	-2

± 1 = LITTLE POSITIVE OR NEGATIVE EFFECT
± 2 = SOME " " " "
± 3 = SIGNIFICANT POSITIVE OR NEGATIVE EFFECT

TABLE 2

THE RELATIVE IMPORTANCE OF SOME

RESPONSES TO VARIOUS SHIP TYPES

RESPONSE	TANKER	BULK CARR.	GENERAL CARGO	RO-RO	CONTAINER
ROLL	1	1	2	3	2
MOTIONS AND ACCELERATIONS	1	2	2	3	2
SHIPPING OF WATER	3	2	3	2	2
SLAMMING	2	2	3	3	3
VERT.BEND. MOMENT	2	2	2	2	3
TORSIONAL MOMENT	1	2	2	1	3

1 = OF LITTLE IMPORTANCE

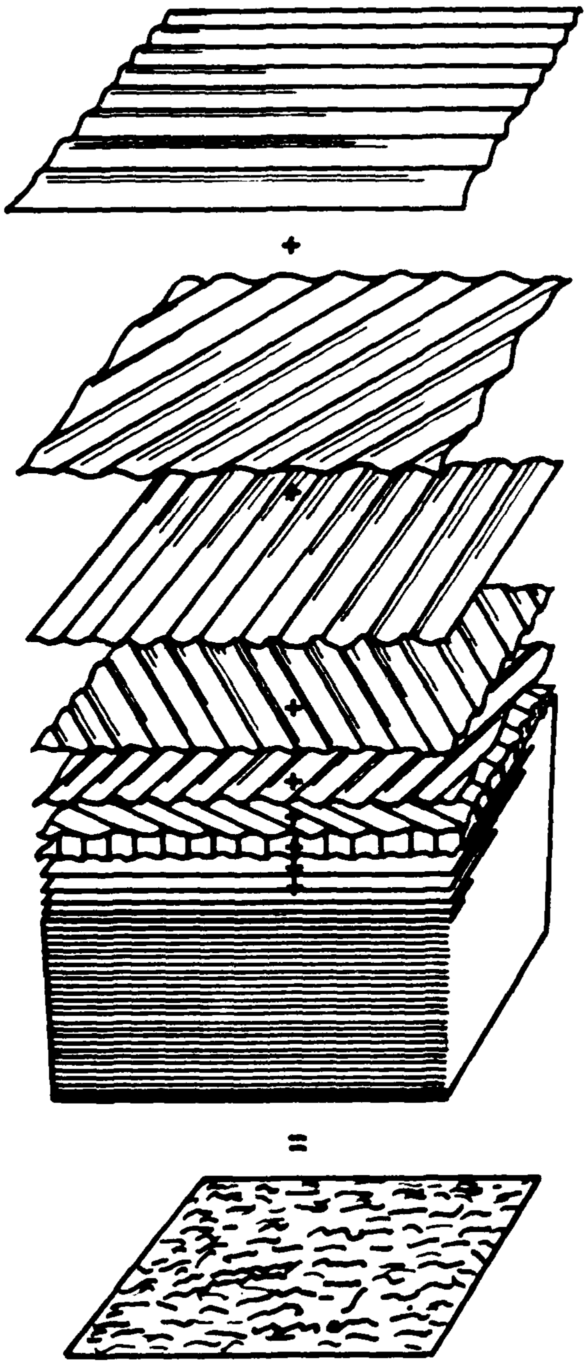
2 = " SOME "

3 = SIGNIFICANT IMPORTANCE

TABLE 3

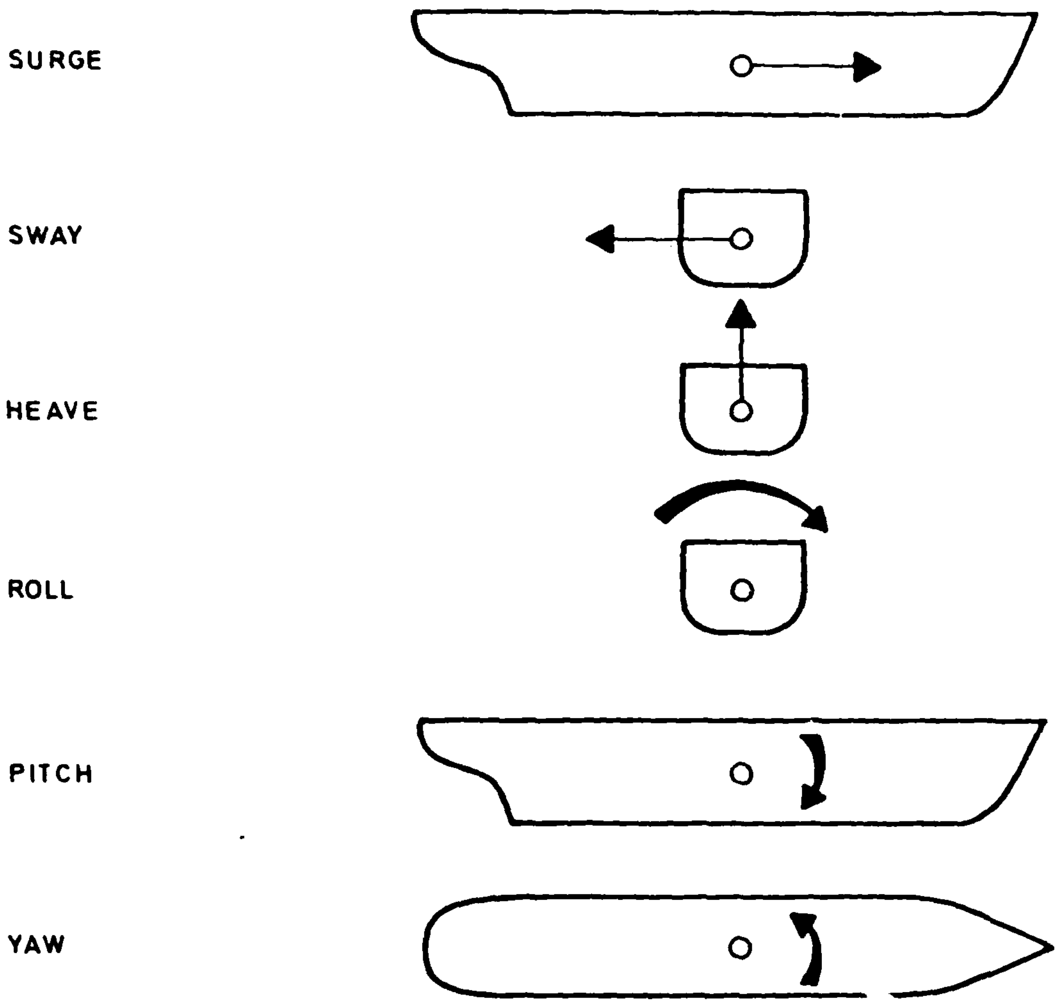
		A	B	C	D
NO	SHIP	PROJECTED LIFE-TIME N/mm^2	LARGEST MEASURED N/mm^2	MATERIAL FACTOR f 1	NUMBER OF RECORDINGS
1	WOLVERINE STATE	62	46	1.00?	4381
2	BOSTON	81	47	1.00?	860
3	CALIFORNIA BEAR	68	39	1.00?	3438
4	UNIVERSE IRELAND	55	33	1.36?	2586
5	ESSO MALAYSIA	52	49	1.36?	3475
6	R. G. FOLLIS	148	64	1.00?	1535
7	FOTINI L	95	60	1.36	2600
8	IDEMITSU MARU	74	29	1.36	1945
9	NORSE QUEEN	93	47	1.36	590
10	HAVKONG	142	61	1.36	338
11	TOYAMA	119	47	1.00?	973
12	ESSO BONN	104	54	1.00	425
13	TAIMYR	87	46	1.00	665
14	BERGE COMMANDER	81	56	1.00	806
	MEAN VALUE	90	48		
	STANDARD DEV	30	10		

TABLE 4 Longitudinal stress levels measured and predicted on 14 ships in service.



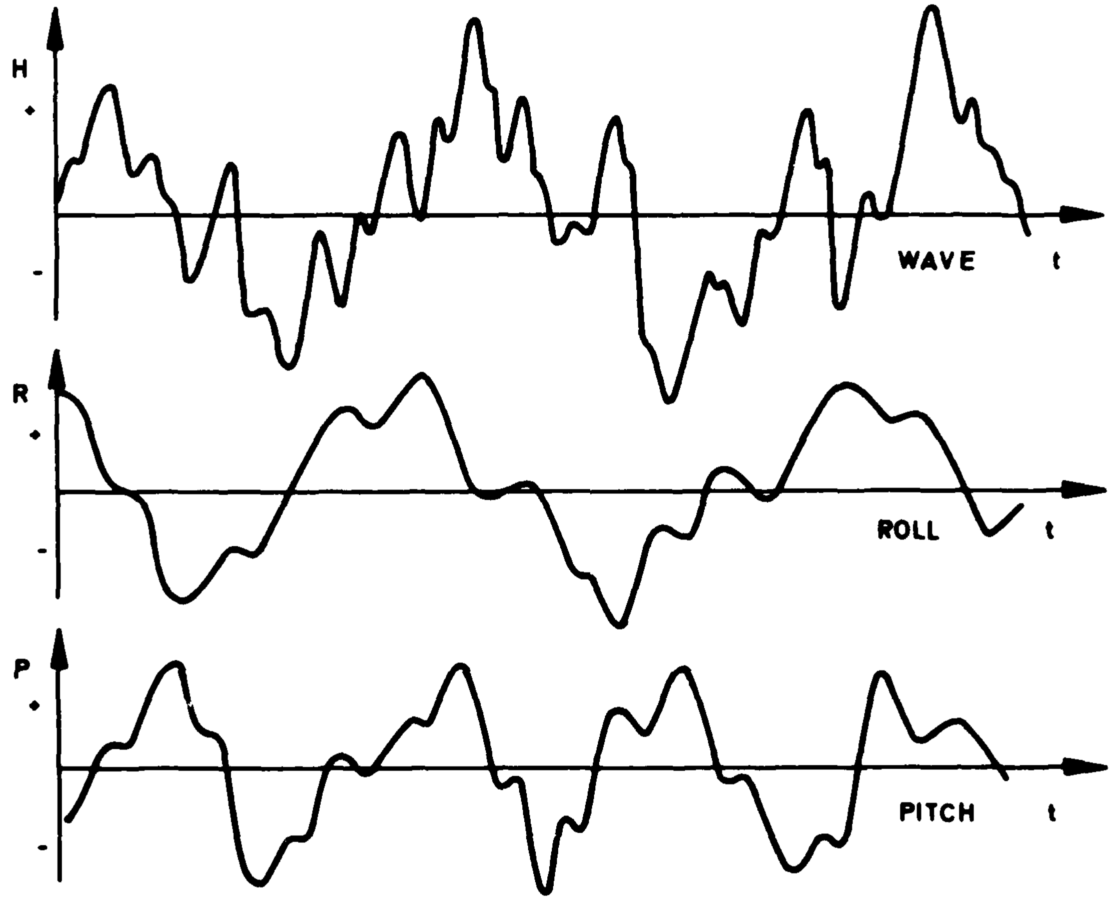
Sea surface after superposition of many regular waves with different amplitudes, wave lengths, and direction of propagation.

Fig. 1



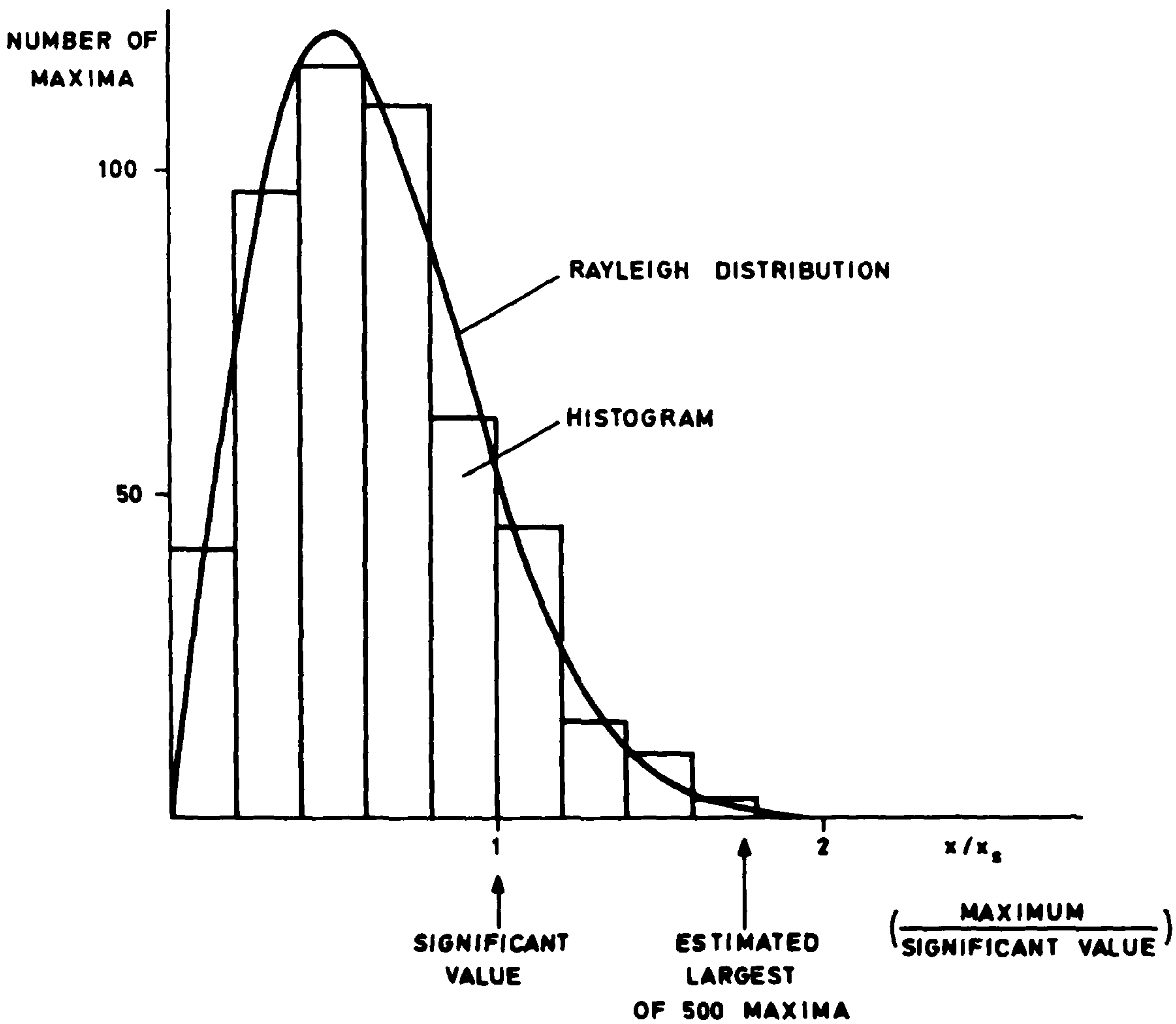
The six degrees of freedom for ship motions.

Fig. 2



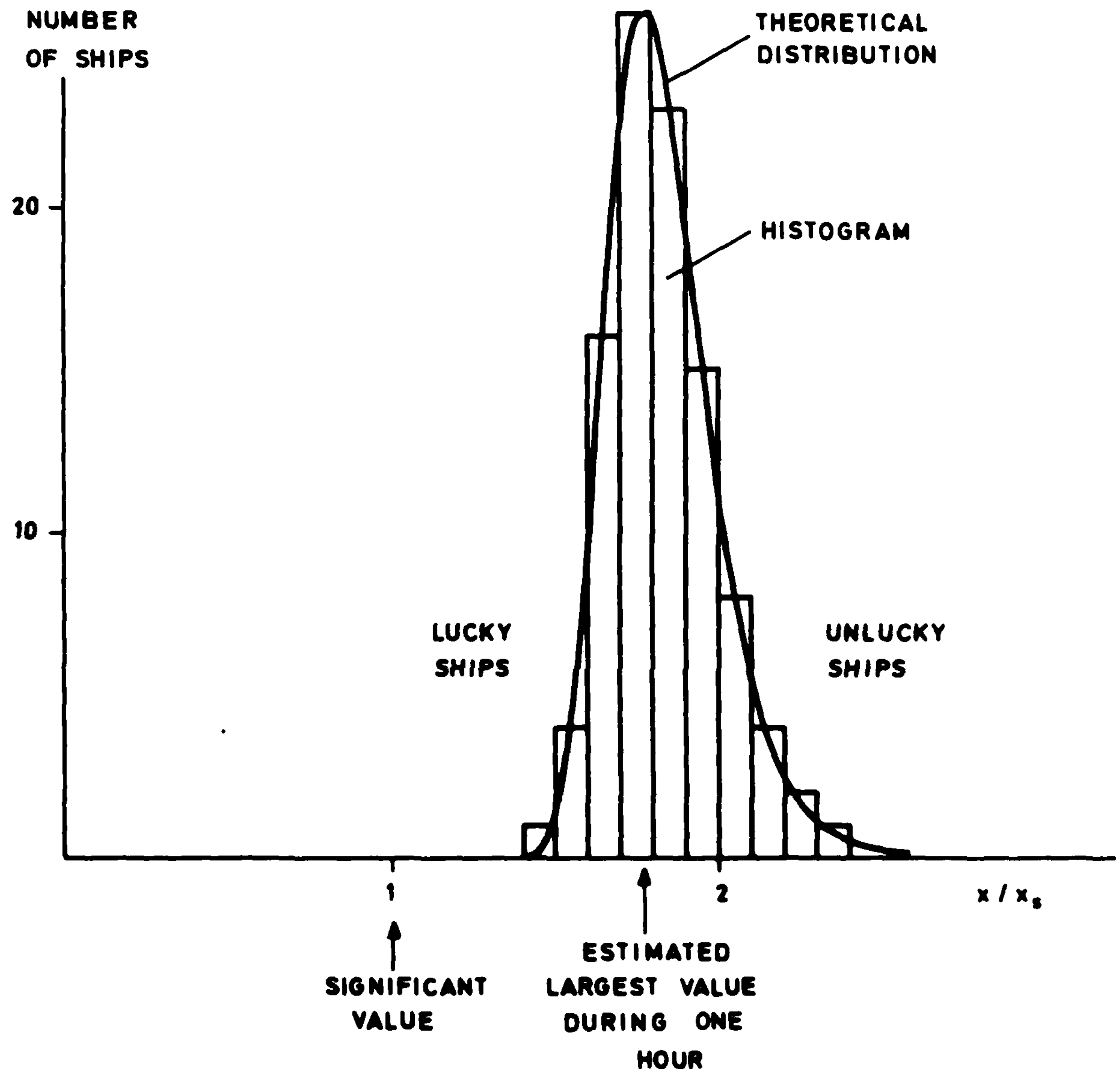
Examples of time traces for the wave elevation, the roll angle, and the pitch angle.

Fig. 3



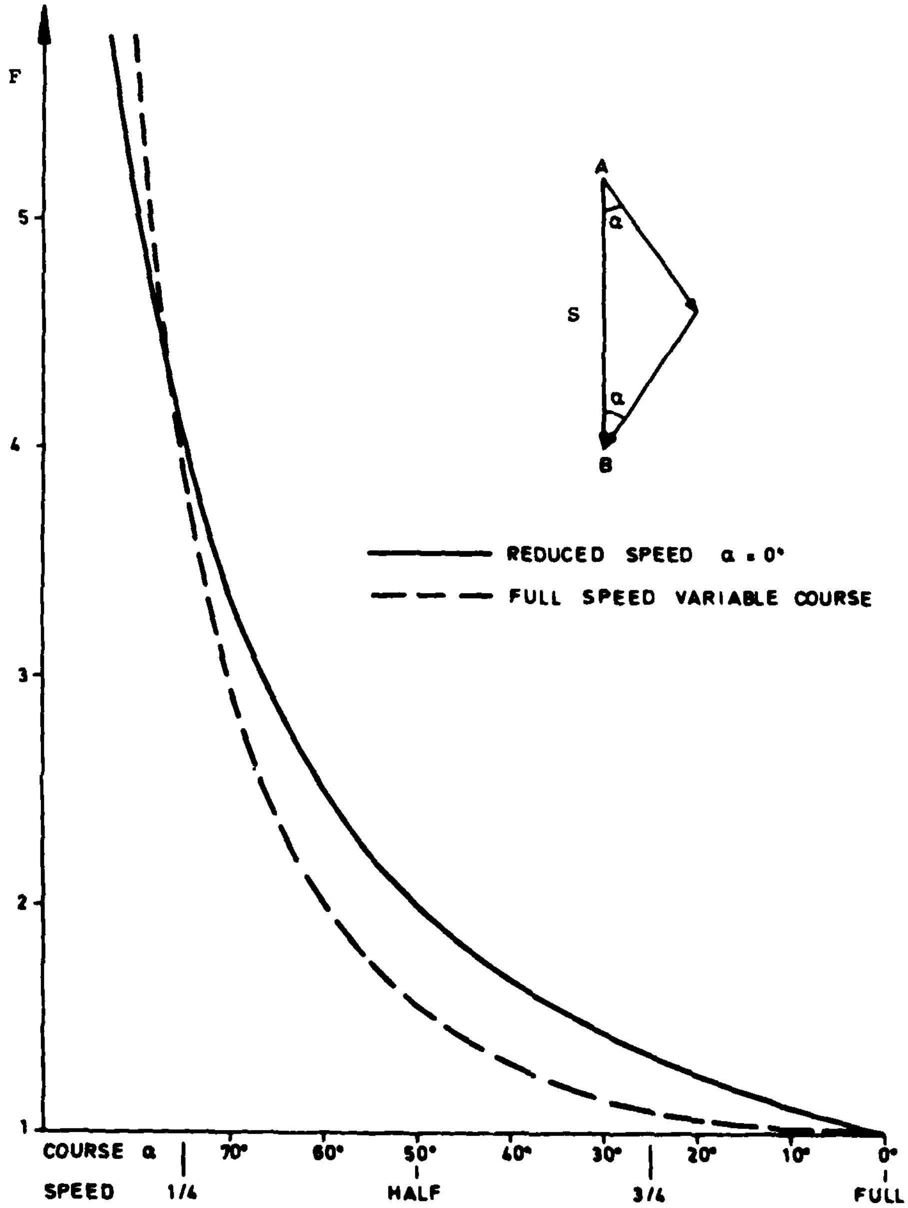
Histogram describing a possible distribution of 500 maxima.

Fig. 4



Histogram describing a possible distribution of the largest value experienced by each one of 100 ships during one hour.

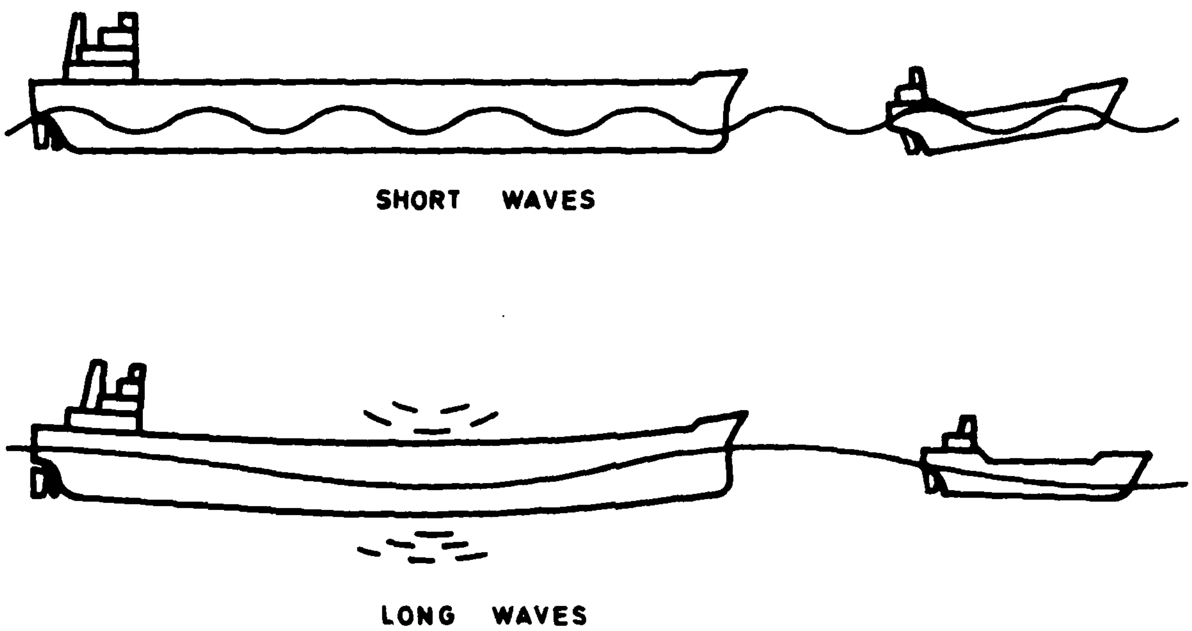
Fig. 5



The time needed to travel from A to B with reduced speed or altered course = FT

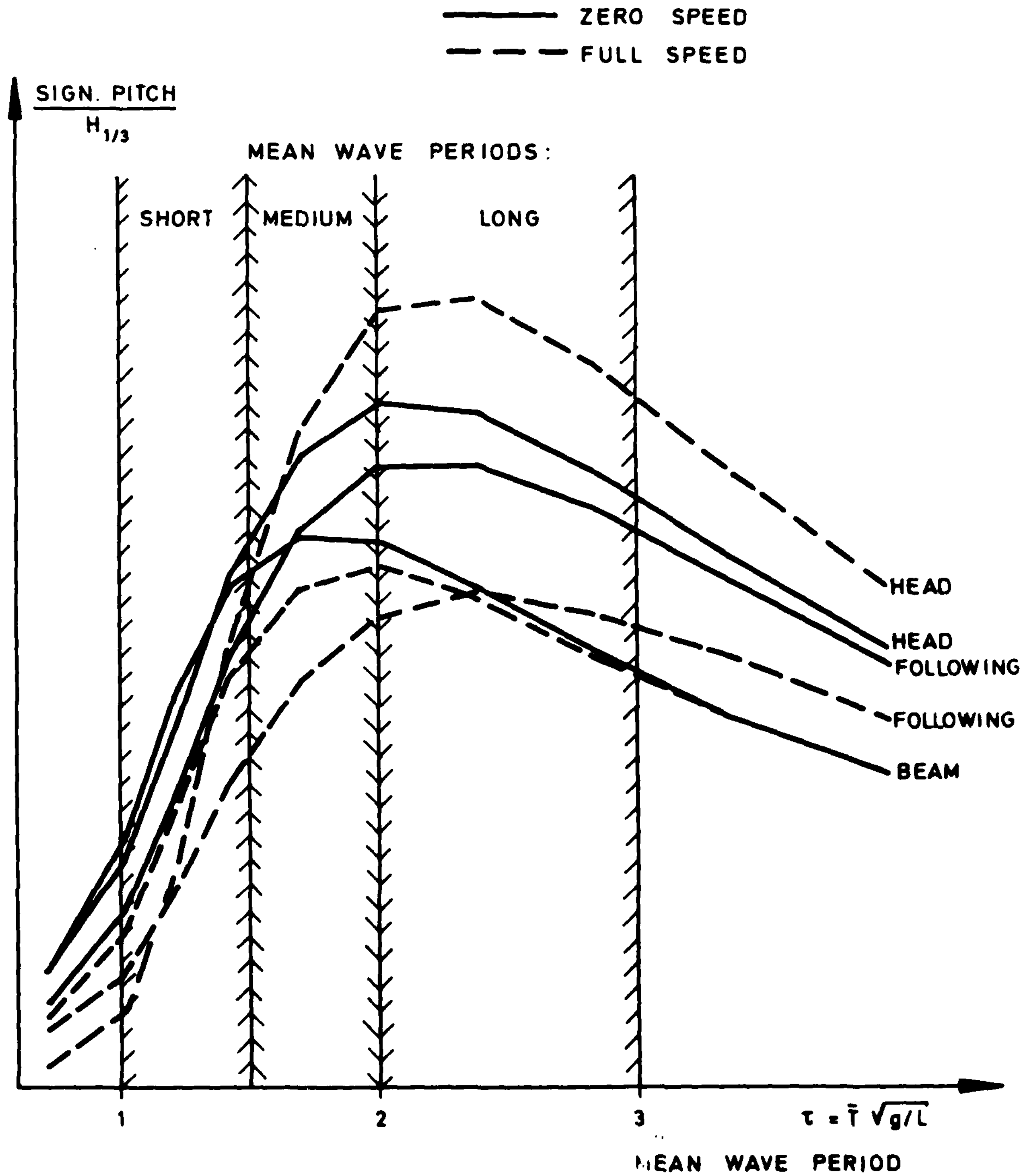
where $T = \frac{\text{Distance S}}{\text{Full Speed}}$

Fig. 6



Influence of the wave length on different ship sizes.

Fig. 7



THE RESPONSE OF PITCH MOTION AS A FUNCTION OF THE MEAN WAVE PERIOD

FIG. 8

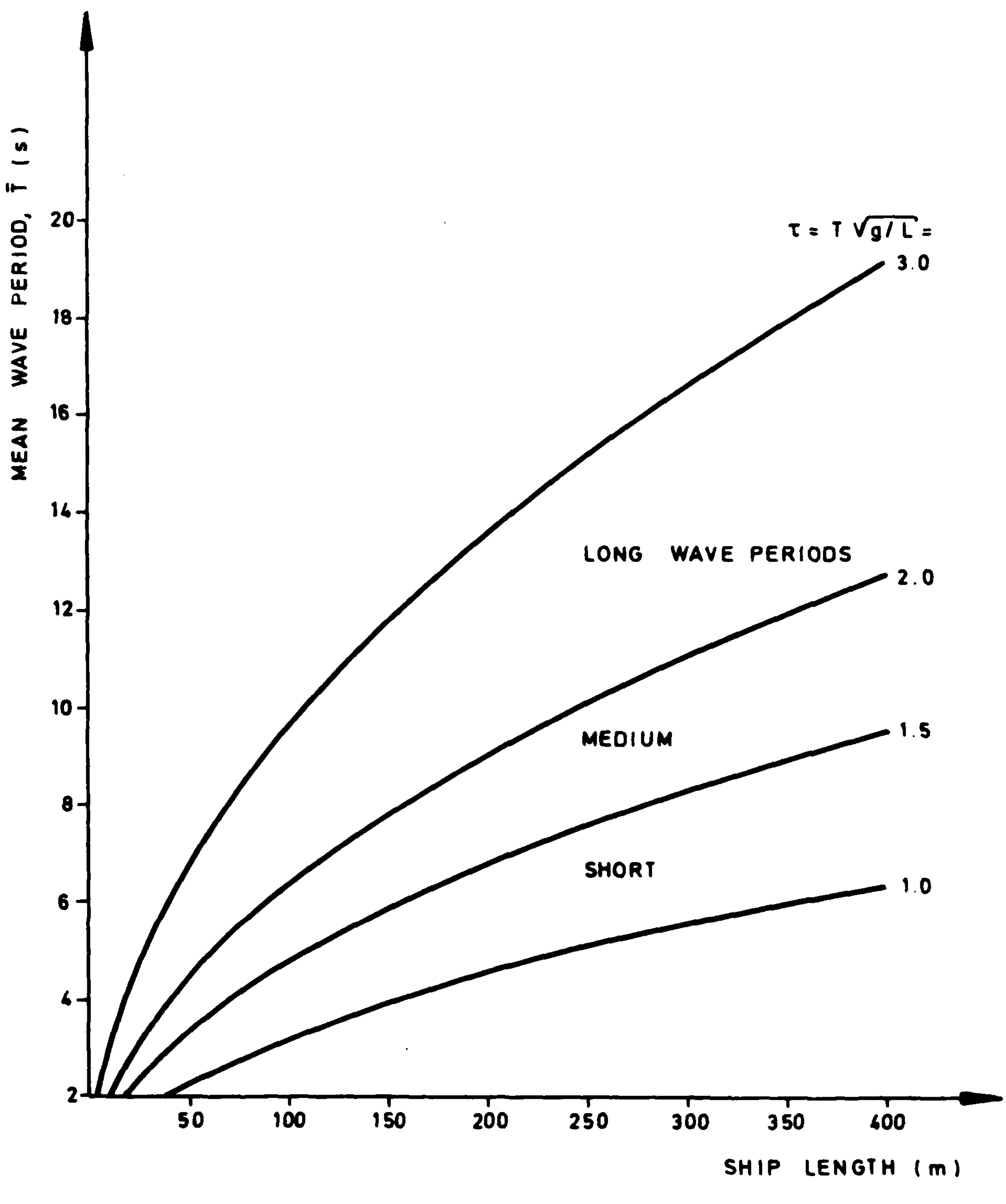

MEAN WAVE PERIOD, $\bar{T}$ (s)
20
18
16
14
12
10
8
6
4
2
$\tau = T\sqrt{g/L} =$
3.0
2.0
1.5
1.0
LONG WAVE PERIODS
MEDIUM
SHORT
50
100
150
200
250
300
350
400
SHIP LENGTH (m)

FIG. 9

GUIDANCE CHART SELECTION FOR VLCC

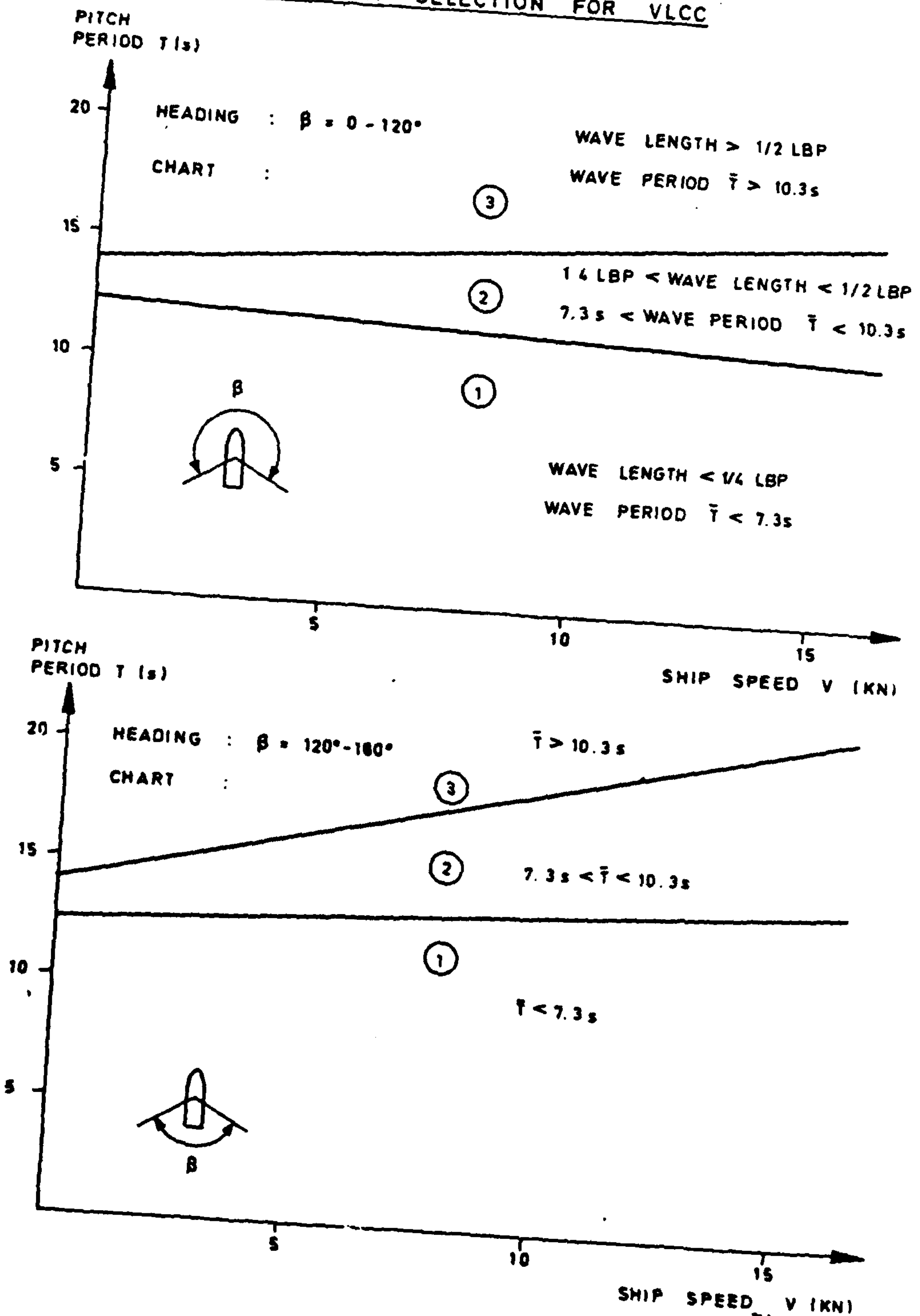


Fig. 10

GUIDANCE CHARTS

1

WAVE LENGTH $<$ 1/4 LBP

WAVE PERIOD $\bar{T} < 7.3\,s$

Fig. 11

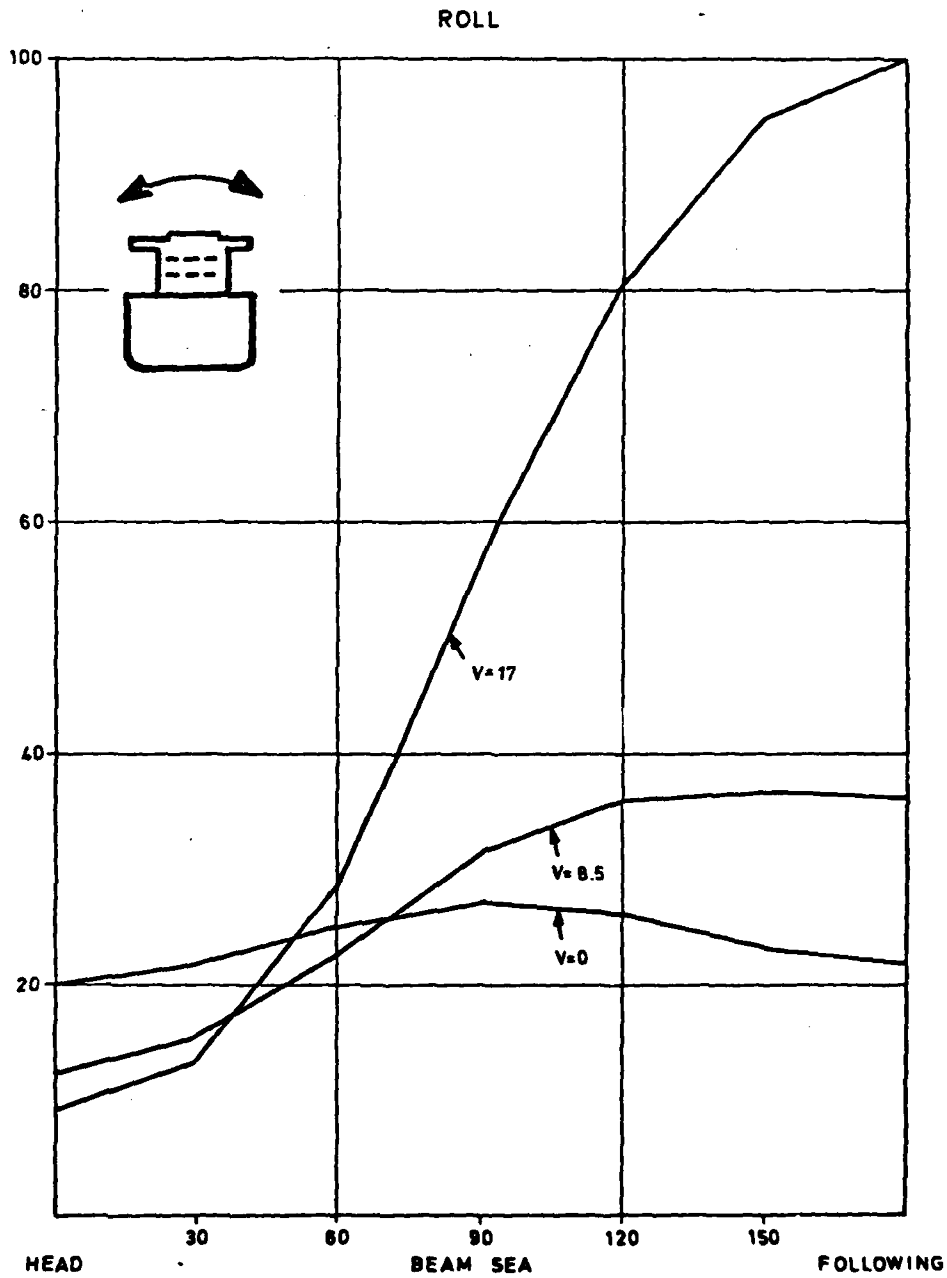
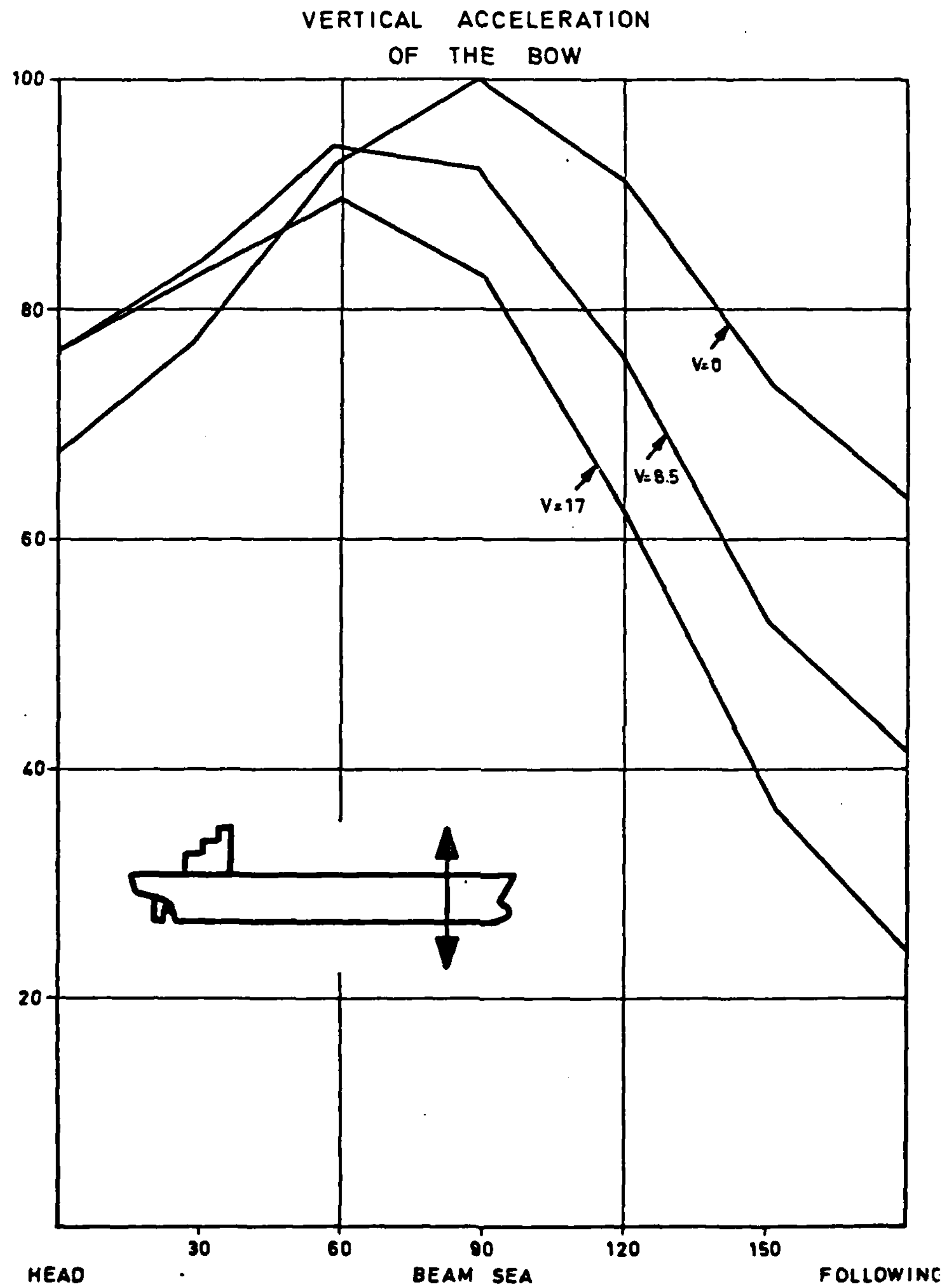

ROLL
100
80
60
40
20
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING
V=17
V=8.5
V=0

Fig. 12



100 = 0.018 g PER METER WAVEHEIGHT

Fig. 13

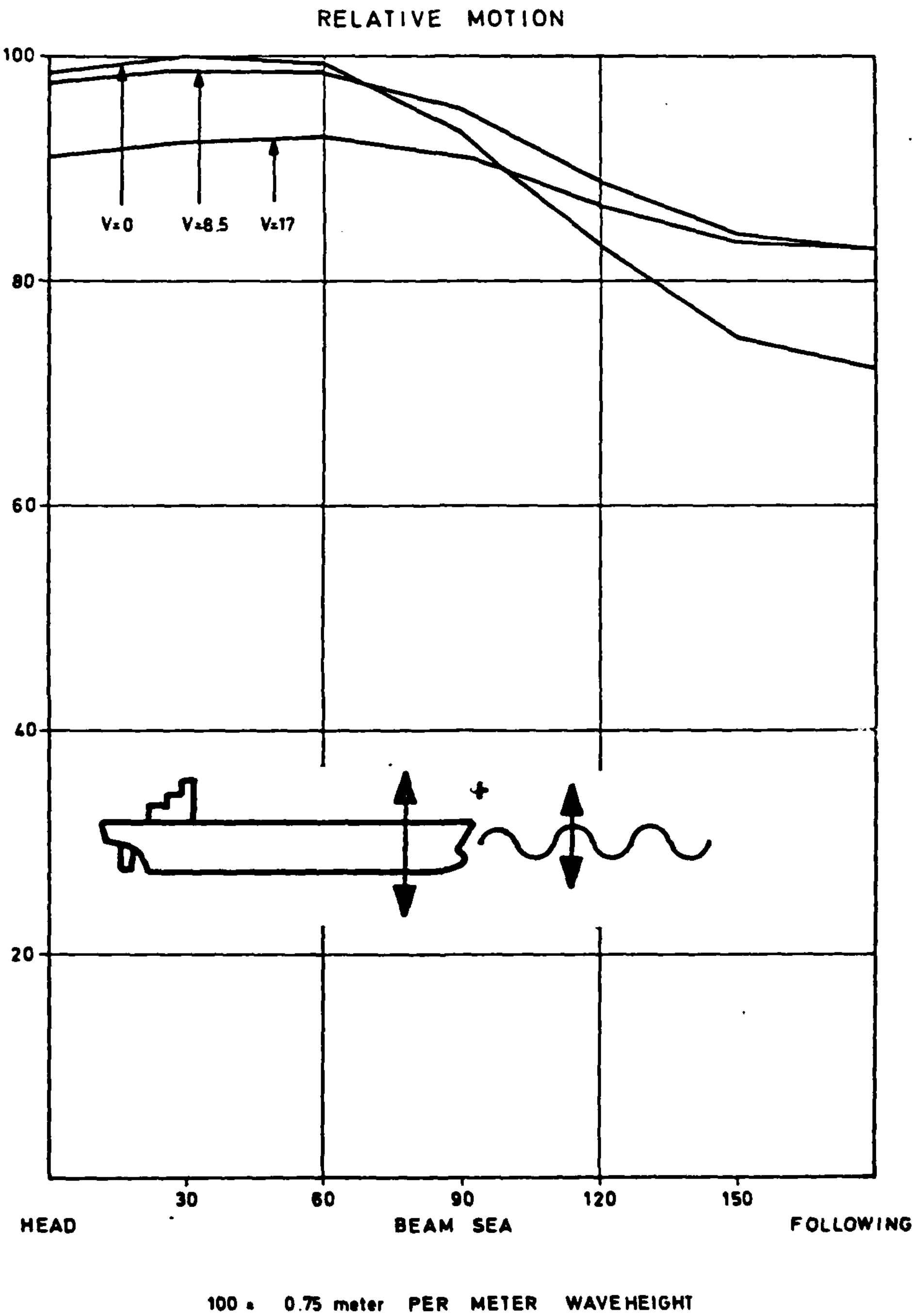

RELATIVE MOTION
100
80
60
40
20
V=0
V=8.5
V=17
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING
100 = 0.75 meter PER METER WAVEHEIGHT

Fig. 14

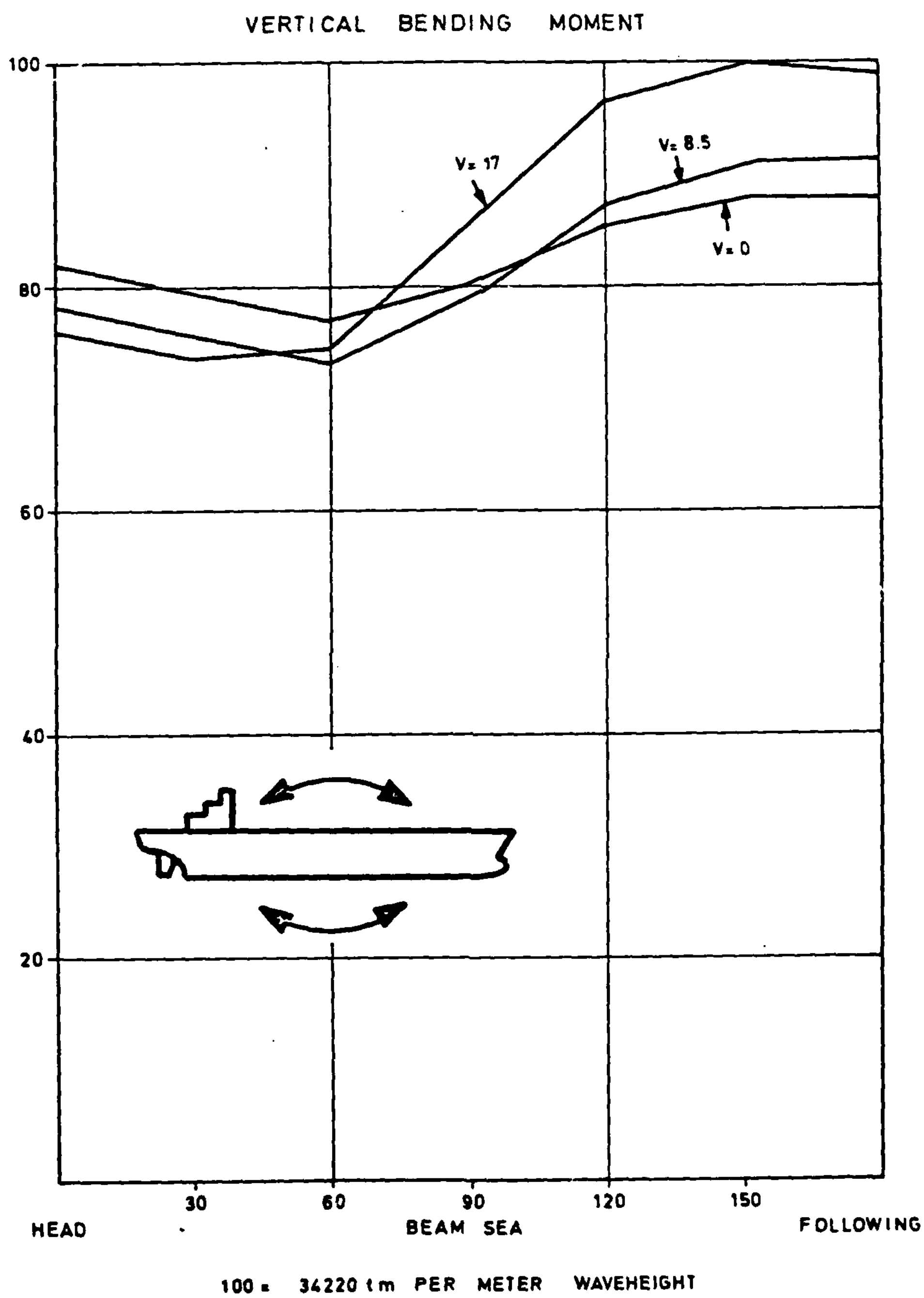
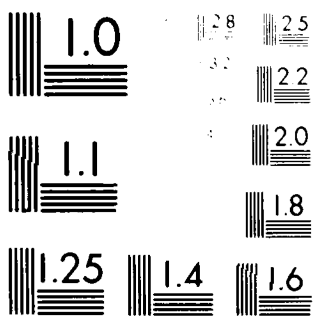

VERTICAL BENDING MOMENT
100
80
60
40
20
V= 17
V= 8.5
V= 0
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING
100 = 34220 tm PER METER WAVEHEIGHT

Fig. 15

AD-A115 176 NORSKE VERITAS OSLO F/G 13/10
SUMMARY OF A COURSE IN SHIPHANDLING IN ROUGH WEATHER.(U)
SEP 81 K LINDEMANN DOT-CG-833401-A
UNCLASSIFIED 81-0782 USCG-M-7-81 NL

2 OF 2

END
DATE
FILMED
07-82
DTIC



MICROCOPY RESOLUTION TEST CHART

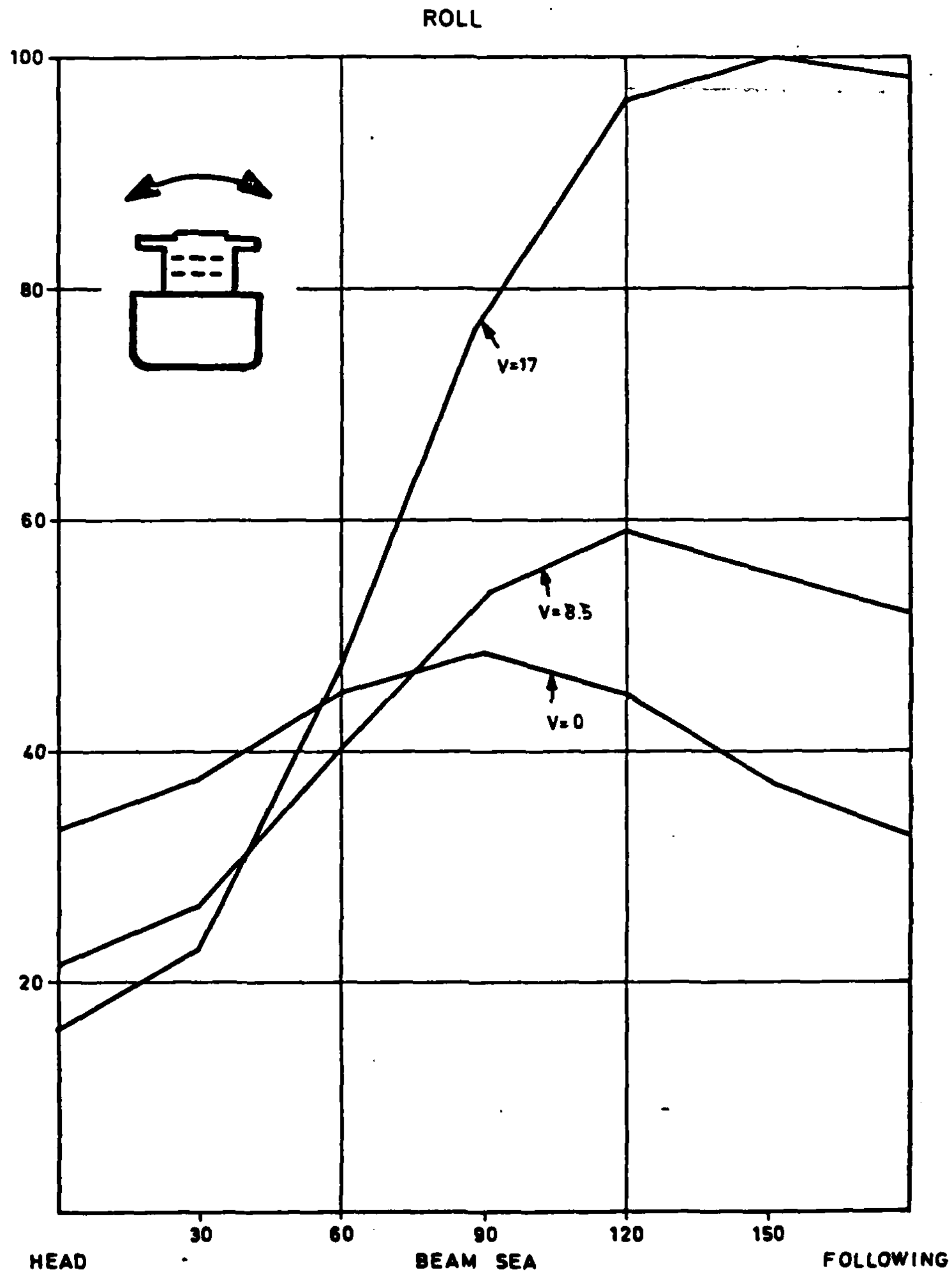
GUIDANCE CHARTS

2

1/4 LBP < WAVE LENGTH < 1/2 LBP

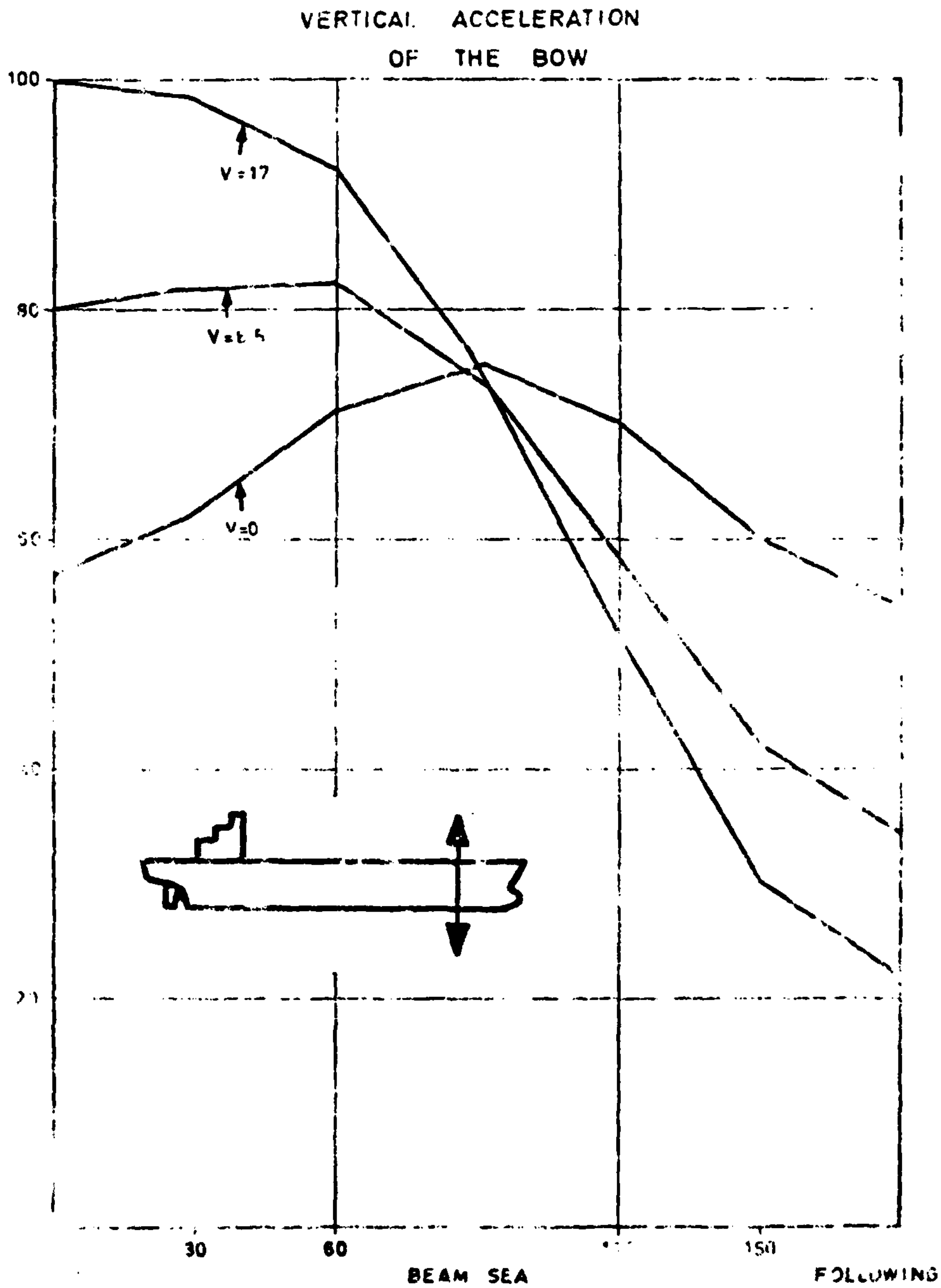
7.3s < WAVE PERIOD $\bar{T}$ < 10.3s

Fig. 16



ROLL
100
80
60
40
20
V=17
V=8.5
V=0
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING

Fig. 17



100 = 0.?24 g PER METER WAVEHEIGHT

Fig. ?9

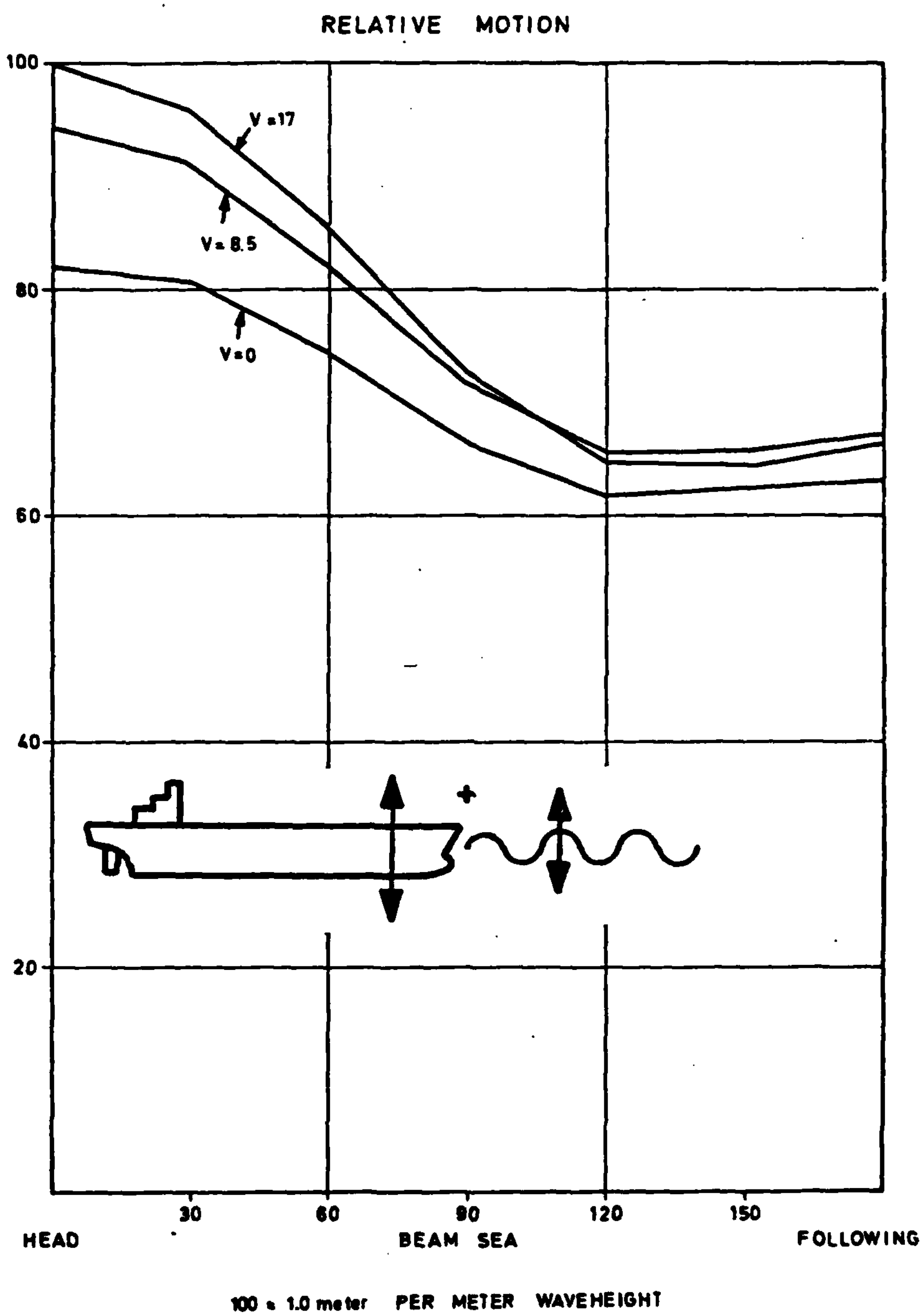

RELATIVE MOTION
100
80
60
40
20
V=17
V=8.5
V=0
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING
100 = 1.0 meter PER METER WAVEHEIGHT

Fig. 19

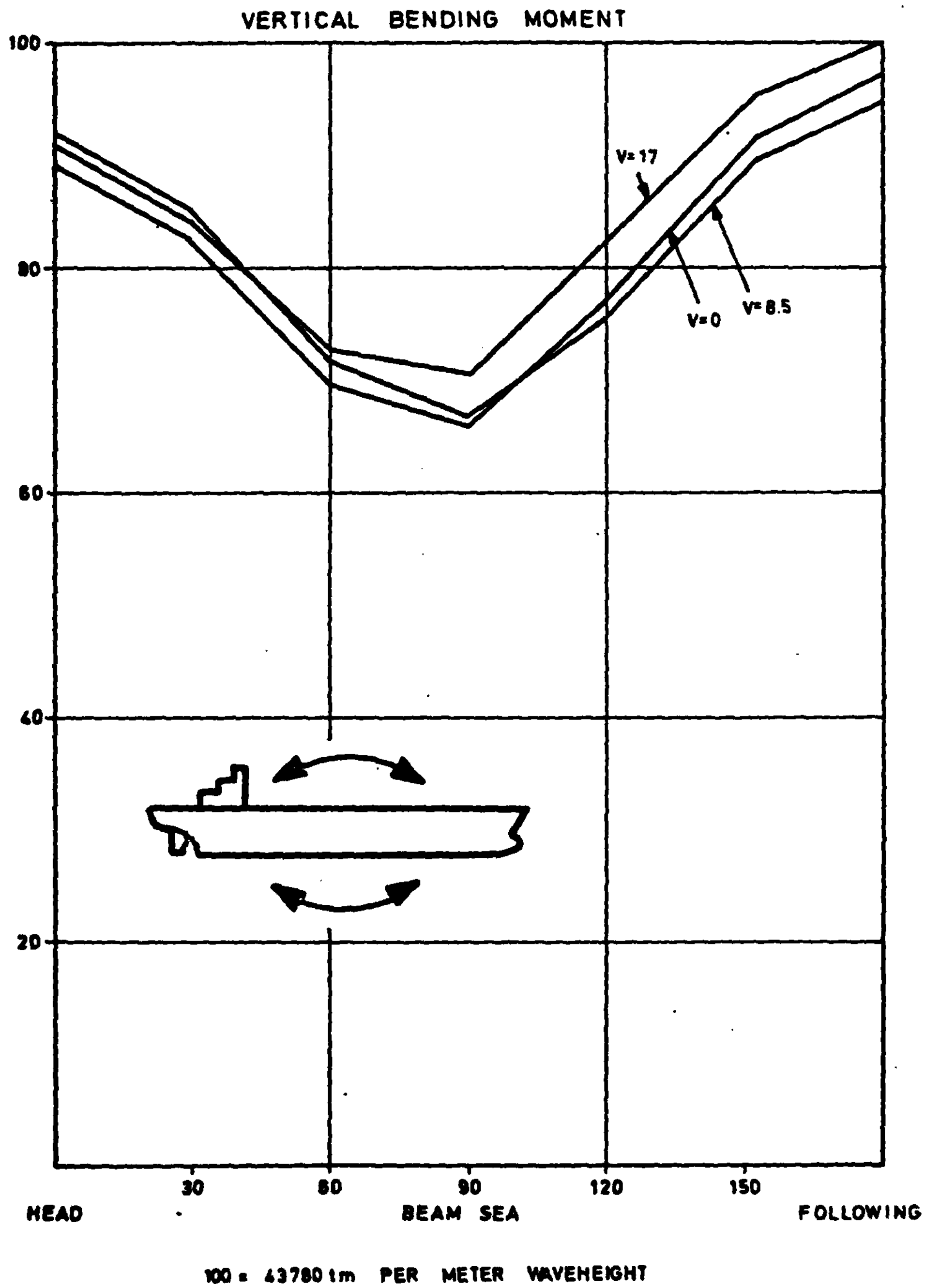

VERTICAL BENDING MOMENT
100
80
60
40
20
V=17
V=0
V=8.5
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING
100 = 43780 tm PER METER WAVEHEIGHT

Fig. 20

GUIDANCE CHARTS

③

WAVE LENGTH > 1/2 LBP

WAVE PERIOD $\bar{T}$ > 10.3s

Fig. 21

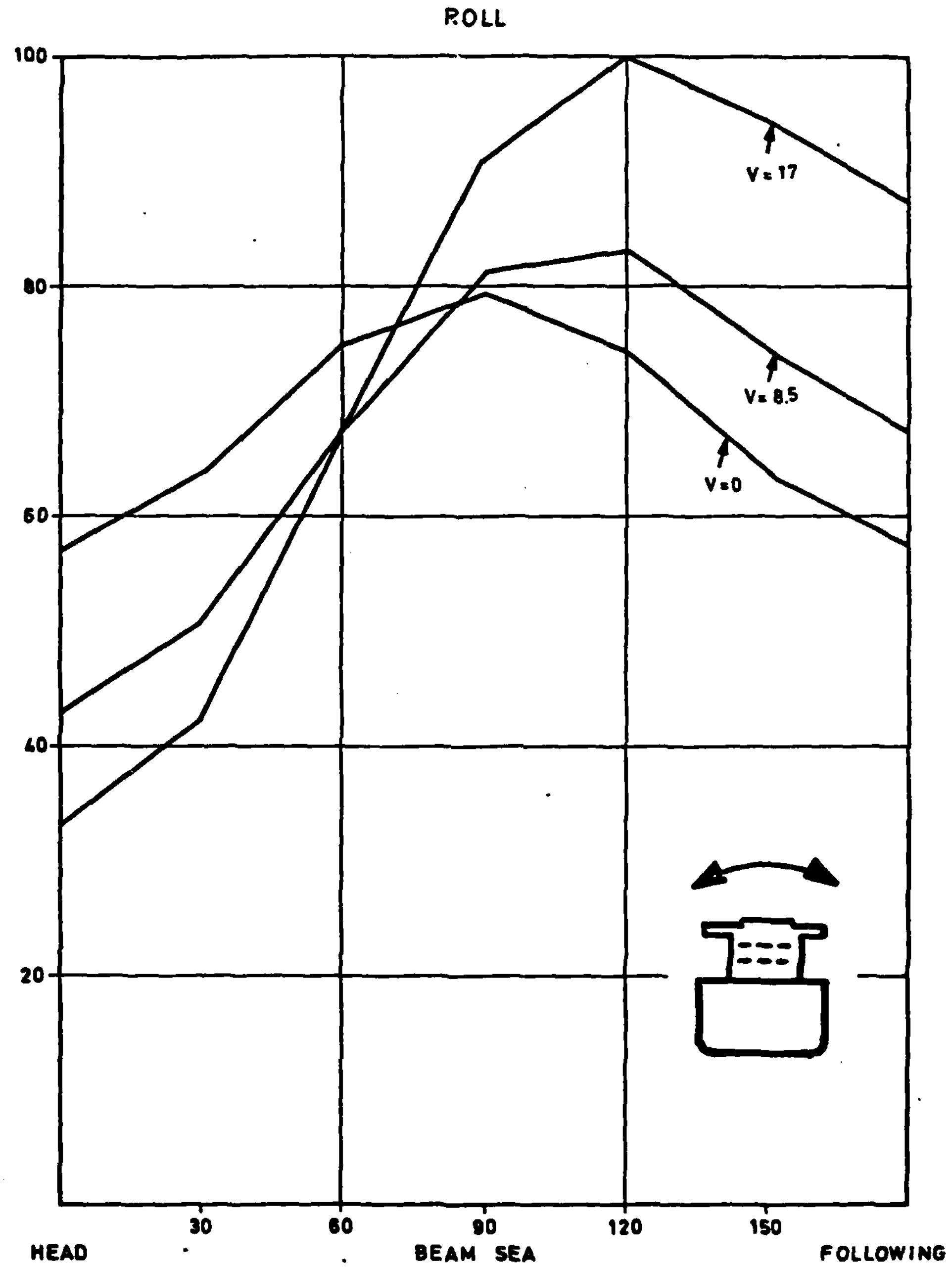

ROLL
100
80
60
40
20
V = 17
V = 8.5
V = 0
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING

Fig. 22

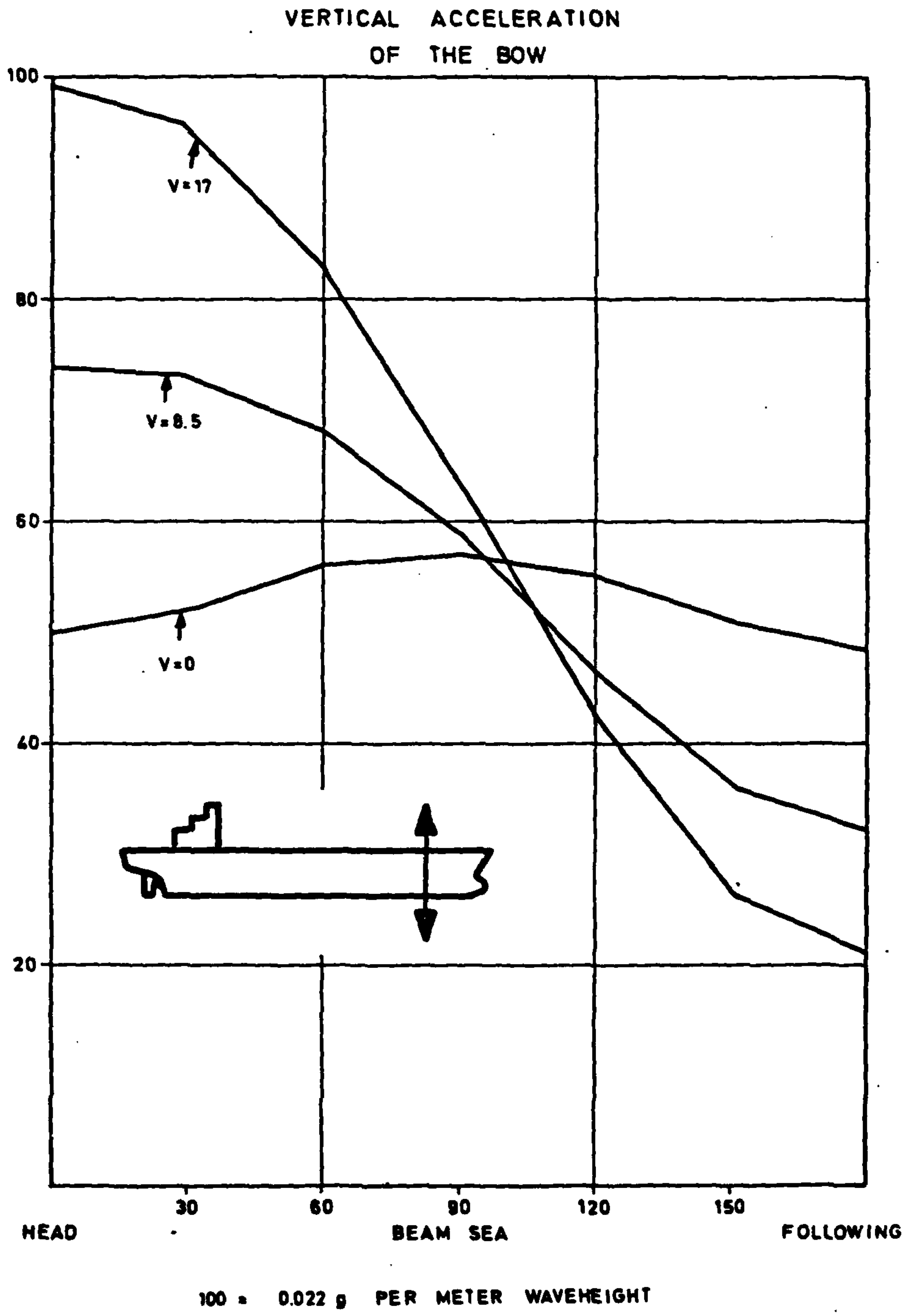

VERTICAL ACCELERATION
OF THE BOW
100
80
60
40
20
V=17
V=8.5
V=0
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING
100 = 0.022 g PER METER WAVEHEIGHT

Fig. 23

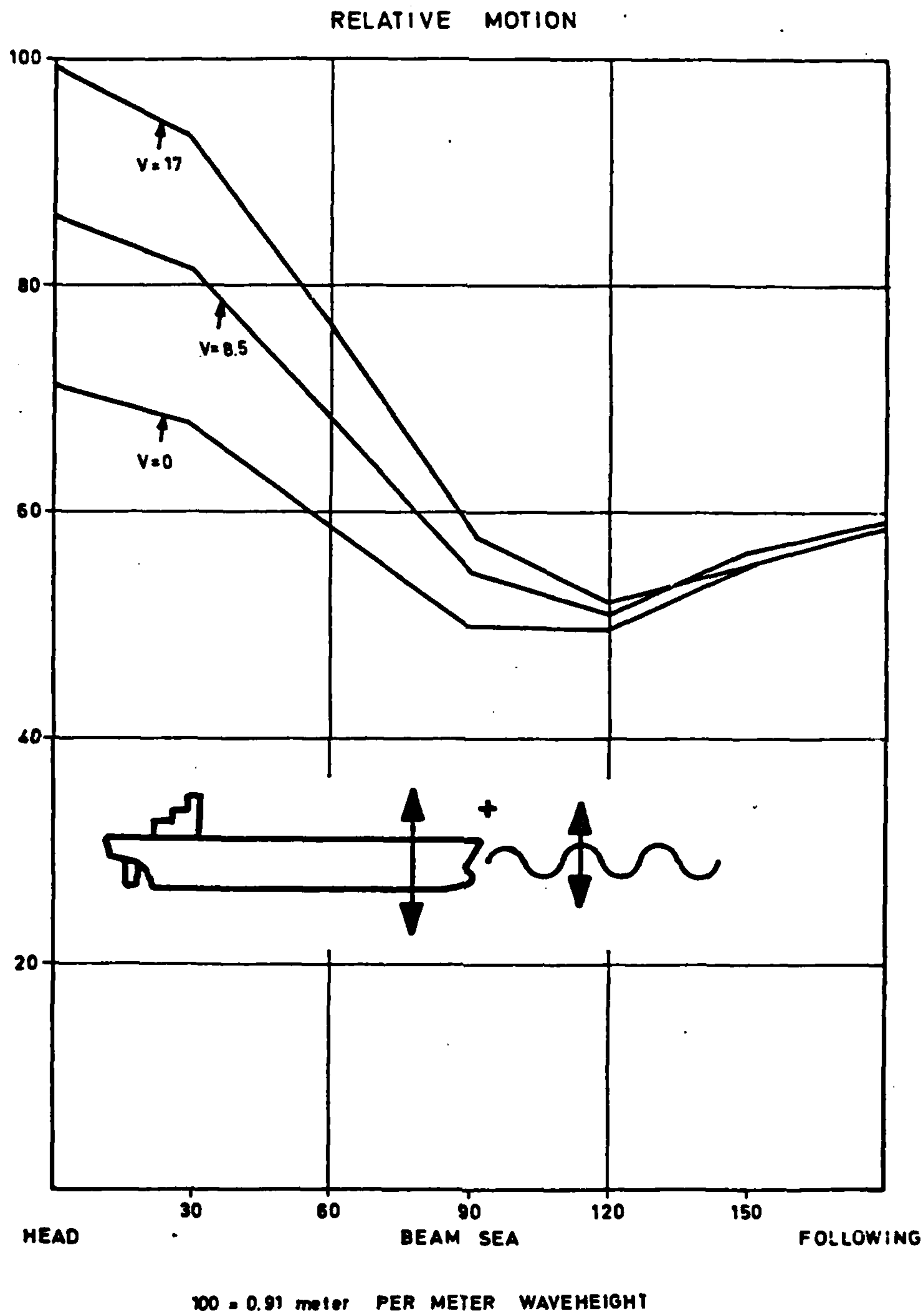

RELATIVE MOTION
100
80
60
40
20
V=17
V=8.5
V=0
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING
100 = 0.91 meter PER METER WAVEHEIGHT

Fig. 24

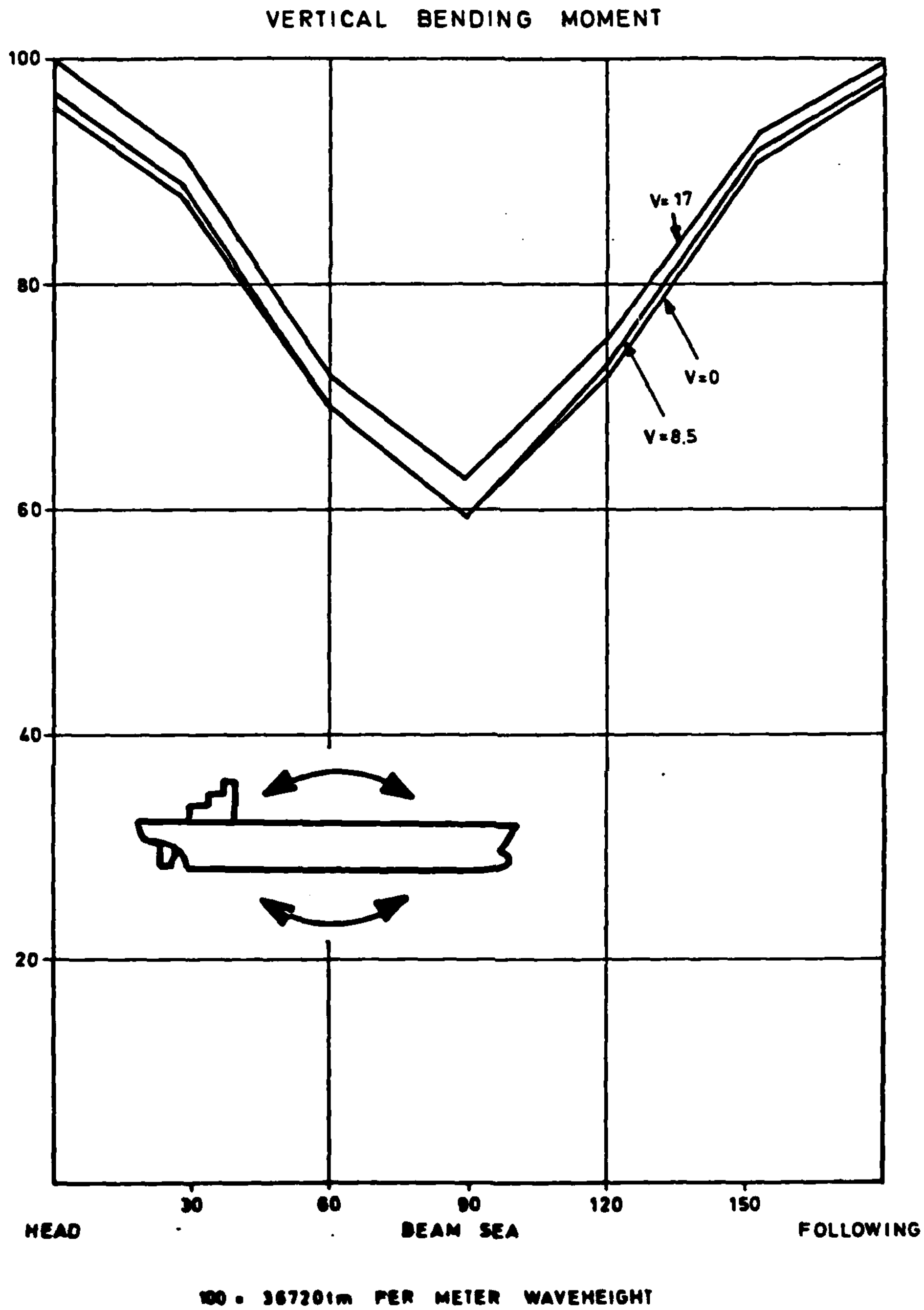

VERTICAL BENDING MOMENT
100
80
60
40
20
V=17
V=0
V=8.5
30
60
90
120
150
HEAD
BEAM SEA
FOLLOWING
100 = 36720tm PER METER WAVEHEIGHT

Fig. 25

APPENDIX B

STATUS REPORT ON THE APPLICATION OF STRESS AND MOTION MONITORING IN MERCHANT VESSELS; by E.A. Chazel Jr., H.P. Cojeen, K. Lindemann and W.M. MacLean. 1980 Spring Meeting/STAR-Symposium. Printed by the permission of the Society of Naval Architects and Marine Engineers.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
One World Trade Center, Suite 1369, New York, N.Y. 10048

Spring Meeting/STAR Symposium, Coronado, California
June 4-6, 1980

Status Report On the Application of Stress and Motion Monitoring in Merchant Vessels

No. 17

Edward A. Chazal, Jr., Member, U.S. Coast Guard, Baltimore, Maryland
H. Paul Cojeen, Associate Member, U.S. Coast Guard, Washington, D.C.
Kaare Lindemann, Visitor, Det Norske Veritas, Oslo, Norway
Walter M. Maclean, Member, National Maritime Research Center, Kings Point, New York

ABSTRACT

There are a number of efforts underway throughout the world maritime communities related to the development and application of stress and motion monitoring systems designed to aid the master and deck officers in making their decisions relating to the safe and efficient operation of their vessels. These efforts are being conducted by maritime technical groups, classification societies, regulatory agencies and shipping companies.

The authors are actively participating in four of these efforts in the United States and Europe. The primary purpose of this paper is to present, in a "non-technical" manner, the technical basis for stress and motions monitoring. The paper is directed primarily toward the potential users of the instruments. An objective presentation of the technological areas that require further study and evaluation has been included. The relations between the sea, the ship and the sailor are discussed following an integrated system approach. The status of these four efforts which are in various levels of development is described. They represented diverse philosophies and concepts in their initial stages.

An attempt is made to address the needs of the potential users, the master and deck officers, with a correlation of those needs to their abilities and responsibilities. This is closely related to the type, quantity and form of the information presented and the factors that control their use of that information. Suggestions as to the degree of training and education required are presented, since in most efforts these important areas are not considered until the end of the instrument development process.

PROLOGUE

This paper was not prepared as a technical document. It was the authors' intent to report on an area of evolutionary progress in modern shipping. This progress has been made through a number of organizations (and in some cases, individuals) working relatively independently of each other but obviously sharing access to the existing level of technical knowledge. "Technical" papers on this subject have been presented in various forums. The community should expect that detailed technical reports will continue to be offered in the future by people who are working in this field.

The authors of this paper are involved in four development efforts. They are the Hull Surveillance (SO3) project supported by the Royal Norwegian Council for Scientific and Industrial Research; and the three Ship Response Monitoring and Guidance Projects managed by the National Maritime Research Center of the U.S. Maritime Administration. The authors recognized that they had some philosophical differences of opinion. They "agreed to disagree" by preparing three independent closure statements to be developed after the main body of the paper was completed. The extent of the epilogue will represent how diverse the authors' philosophies remain after collaboration on this paper.

In order to insure that a full dicussion was obtained, written discussions have been sought from a variety of people, including, perhaps most importantly, the masters of ships who have had experience with the experimental versions of the systems under development, as well as other persons in the marine field who might be called upon to use or recommend use of instrumentation systems.

INTRODUCTION

"Water covers more than two-thirds of the earth; man had to find his way across it. And so, down the ages, man with his ingenuity and his courage fashioned the ship - free, charged with the strength and grace and poetry of the singing sea. And where once dugout and raft, galley and galleon, tall clipper and beamy paddle-wheeler traded the sea, now swift freighters, mammoth tankers, luxurious liners and cruise ships steam in endless movement around the world, bearing man's cargoes, his hopes, himself." (Villiars, 1973)

This is an evolutionary report. The ships of our times are magnificent engineering marvels. The men who sail them often use the most sophisticated technology to complete their tasks. However, to be true to ourselves, it must be recognized that for all our vaunted science, engineering, and technology, man is still at the mercy of the awesome power of the nature he has sought to tame. We must be reminded of the historical development of shipping - much of it obscured in antiquity because sailing preceeded writing.

250,000 DWT Tankship Operating in Heavy Weather. (Courtesy of Frank Mueller-May)

".....(ship's officers) must realize that in bad weather, as in most other situations, safety and fatal hazard are not separated by any boundary line, but shade gradually from one into the other. There is no little red light which is going to flash on and inform commanding officers that from then on there is extreme danger from the weather, and that measures for the ship's safety must now take precedence over further efforts......"

Admiral Nimitz, following the loss of three destroyers of Halsey's Third Fleet in a typhoon east of the Philippines on 17 and 18 December 1944

There are still places in the world where a man is at one the designer, builder, and navigator of his craft, which has survived since prehistoric times. Today, in the remote reaches of Asia, the traveler will cross a stream on an inflated hide. The dugout canoe still serves in many parts of the world. The curragh of Ireland, the coracles of Wales have survived, virtually unchanged since the Roman conquest of Britain two millenia ago.

No one knows who extended the sides of a dugout by planking to increase freeboard. When was the beam broadened to increase capacity and stability? Our mighty leviathans of today owe as much to the trial and error process or ingenuity of man, as they do to modern "scientific" methods.

The arts of navigation and seamanship have a similar development. Many a rocky shore offers testament to a failure to navigate properly. Many an unsearched depth hides the residue of less than prudent seamanship. Navigation and seamanship, the combination of these two arts by the master provides the strategy which he develops to achieve the goals of his voyage. Such a strategy may require constant refinement depending on the changing circumstances.

For centuries, navigation in Europe meant pilotage and dead reckoning. Coupled with the superstitions of the times, this had hindered commerce. By importing the knowledge of other cultures to his retreat at Sagres on the southwest coast of Portugal, Prince Henry in the 15th century wrought a revolution in European trade and opened the world for the regular use of the oceans for commerce on a unified global scale. Improvements in charts, navigational instruments, and, most importantly, the attitudes of sailors were Henry's contributions. Modern commercial development was his legacy.

The advent of better ships, better navigational instruments, and more knowledgeable crews improved ocean transport productivity but did not prevent losses. The joyous celebrations of a returning fleet and crew were often marred by the losses of ships and crews. Even today there are blunt reminders of the vagaries of the sea and the dangers to those who sail upon it.

Mariners have sought to improve their odds of survival. The compass, sounding lead, wood chips (or log) and hour glass were developed. Now, the gyro compass offers a higher resolution in direction: fathometers, chronometers, doppler and pit logs offer the same for depth, time and speed measurements. Radar supplements the traditional look out. The sextant offers better accuracy than the astrolabe. Radio direction finders, Loran, Decca, Omega, and Satellite Navigation Systems provide improvements in navigational accuracy and flexibility in all weather conditions. Improved communication provides more current meteorological information to the ship at sea. Forecasters themselves benefit from the global weather view of satellites that augment the finite number of surface weather observations.

The historical apprenticeship programs of mariners have evolved into the modern system of schools and professional licensing. Standards of adequacy are decidedly more international as global interests bridge the gaps of national differences. The technical complexities of a modern ship place even greater demands on the sailor to expand intellectually beyond the traditional concepts of being a seaman and navigator.

The loss of a ship 20 years ago would have been viewed more in the perspective of prior recorded and unrecorded history. The human loss would be associated with the grief of relatives and friends of the crew. The financial loss would be limited to ship backers and those who owned or were consigned the cargo. Today's technology, when it fails, has broader reaching effects. Only time will reveal the total impact of the steering failure on the AMOCO CADIZ. The social consequences are as yet undefined, but many more lives will be touched than would be traditionally associated with such a tragedy. In spite of technology and, indeed, because of it, the modern sailor must accept an ever increasing responsibility not only for his own well-being and the safety of his ship but for maintenance of nature's precious balance as well. Simultaneously, the goals of productivity and effiency in ocean transportation should be served lest the commercial aspects of the venture will be unsuccessful.

This report is written in the broadest sense of historical perspective. The reader should incorporate his own sense of history into our short narrative. Western civilization has evolved into an energy intensive society. The riches of the east are no longer the spices of Henry's day but rather energy products that can be cheaply produced (if not cheaply sold!). How ironic that the route around the African Cape, envisioned by Henry and sailed by his captains, remains a principal trade route for the modern riches of the East.

The need to transport energy resources at the lowest possible cost from its source to the places of its use has brought a great challenge to the art of seamanship. Science and engineering made use of the economies of scale to build ever larger ships. The modern age brought unquestioned advances in ship design, shipbuilding technology, and even navigation. The modern mariner has an impressive list of tools to assist him in safely completing his voyage, yet he has had the inherent utility of his senses diminished.

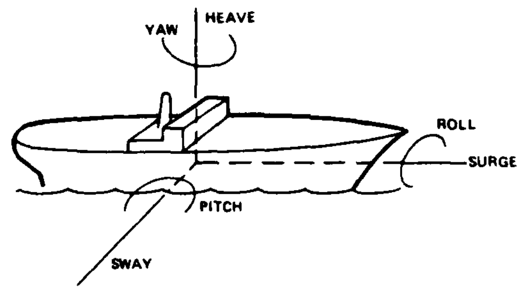


FIGURE 1. THE SIX DEGREES OF FREEDOM.

The evolutionary development of naval architecture has incorporated within its design guides the basic premise of "prudent seamanship." Ships are not now, never have been, and probably never will be failure proof. There is a failure point for all ships whether it is a matter of stability, structural integrity, or the capacity to maneuver. Traditionally, sailors, through experience, have developed a "feel for the sea". It is a nearly mysterious quality which enables a man to sense by the motion of the deck, the sounds of the wind in the rigging or the groans of the timbers, the remaining capacity of his craft to survive. These senses survive even today on many forms of ships. Even the larger riveted hulls prior to the 1940's would "work" and provide some sense of danger. The advent of all welded construction and the larger size of many modern ships tend to mask many of the traditional sensory signals. Fortunately, the technology which yielded the data needed to design the new generation of ships - statistics, instrumentation, and computers - also offers the means to restore a measure of "feel for the sea" to our modern sailor.

BACKGROUND

A ship is a floating body propelled by some means over an everchanging water surface. It is subjected to various environmental loads - some atmospheric, some hydrodynamic. It is also influenced by self-generated forces such as propulsion and a variety of on-board dead and live loads such as cargo, sloshing liquids, and vibrating machinery.

As a floating body, a ship has six degrees of freedom. It can translate in any combination of directions - surge, heave, and sway, as illustrated by Figure 1. It is also capable of rotation about the translational axes - roll, yaw, and pitch. Any force upsetting the equilibrium will cause an acceleration, velocity, and a translation (or rotation) from the prior

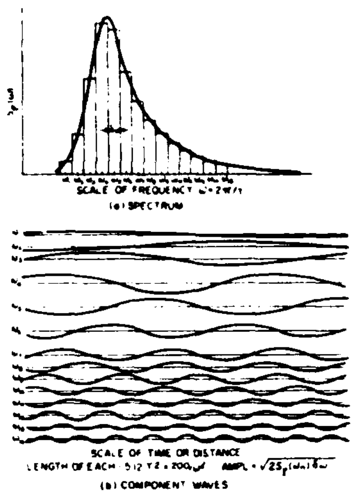


FIGURE 2. TYPICAL ENERGY SPECTRUM, SHOWING APPROXIMATION BY A FINITE SUM OF COMPONENTS (from Principals of Naval Architecture, 1967).

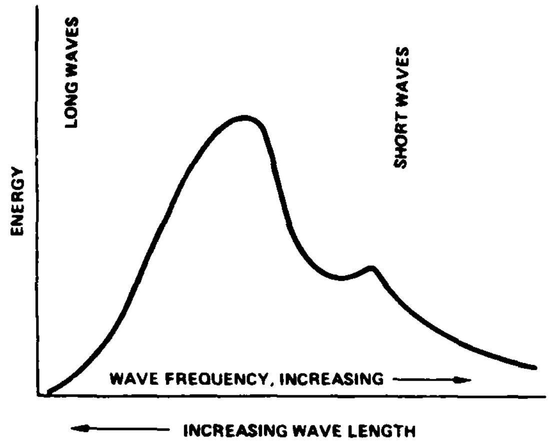


FIGURE 3. REPRESENTATIVE SPECTRUM FOR 40 KNOT WIND.

position. A ship in a seaway constantly experiences a combination of all components of motion. These are termed motion responses.

As masters can attest, a ship is not a rigid body. It can bend, twist, and otherwise distort. These may be broadly classed as the structural responses. The structural responses are due to the same forces which produced the motion responses. However, there are also loads imposed by the internal distribution of weight, inertial reaction to accelerations of the motion responses, machinery reactions, and other similar internal sources. The structural responses are intended in most designs to be within the elastic range. In cases of extreme loading, local plastic yielding may occur and permanent deformation result.

The master utilizes all the available response information in conjunction with his assessment of the weather and sea to safely bring his ship to port. Sensory instruments such as accelerometers and gyros can provide an electrical signal to provide measurements of any or all of the six degrees of motion freedom. Distortions can be measured using strain gages. Sailors performed the same sensory function by visually observing motion and detecting acceleration through their own inner ear equilibrium mechanism. Strains could be both seen and heard as the hull was twisted and bent - to use the sailors' term "worked in the sea." Anyone who has experienced a storm at sea in a small to moderate sized ship can conjure up vivid memories of these sensations. This paper will discuss this ability to measure heave, pitch, roll and the vessel distortions. The motions of larger ships which are masked to the human sensations can be measured by electronic means. The computations that are necessary to express the results in a manner understandable to a ship's master are accommodated by small, relatively cheap computers.

Response sensing instrumentation and the computational equipment to analyze and interpret conditions are simply a tool for prudent seamanship. They provide information for the discretionary guidance of the sailor - just as the various electronic navigation systems supplement the traditional celestial, pilotage, and dead reckoning forms of navigation. The systems augment the sailors' own senses for the traditional "feel of the sea" and "working of the ship" even as radar extends the range of his eyes and ears to detect impediments to safe passage. There are alternate means of providing information to the master. Wholesale generation of computer output might excite an instrumentation or computer oriented engineer but have no meaning to the deck officer. He justifiably needs data in a form he can readily use for decision making with minimal risk of misinterpretation. Since any system is subject to failure it is important to have a means for detecting malfunctions.

The instrumentation systems to be discussed in the later sections of the paper are in various stages of development. The technology and manner of application are directed toward providing reliable and useful sensory information. At some point initial development will cease and application will take place. There are those who favor mandatory adoption (NTSB, TEXACO OKLAHOMA, and OCEAN EXPRESS) of forms of these devices as a means of casualty prevention. Unfortunately, as with any human endeavor, there will always be an element of risk. In spite of all modern navigation aids, ships are still run aground. In spite of the extended eyes of radar, collisions take place. At some point a ship equipped with response sensing equipment will experience a casualty. The mere addition of a device, no matter how useful, cannot prevent a casualty from occurring. There is always the danger that such devices may tend to desensitize the user to the point where he would act less prudently. Properly installed and used, however, the risk can be mininized and vessel productivity enhanced. It can not in the foreseeable future subsititute for an alert, trained and intelligent human decisionmaker - the ship's master.

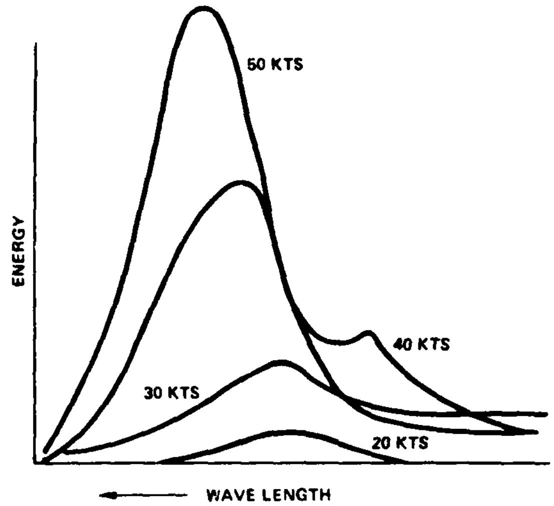


FIGURE 4. REPRESENTATIVE FAMILY OF SPECTRA BASED ON SUSTAINED WIND VELOCITY.

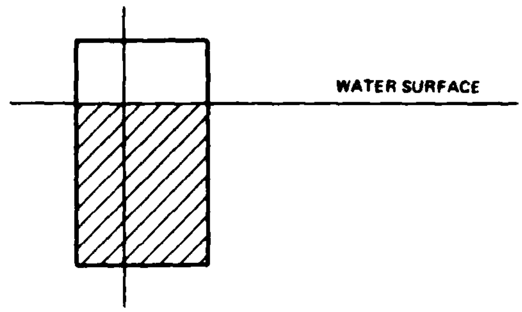


FIGURE 5. BUOY FLOATING IN STATIC EQUILIBRIUM

CONCEPT

The purpose of this section is to provide a practical understanding of pertinent principles of oceanography, hydrodynamics, seakeeping, and human psychology. It is written in basic terms solely to establish the common grounds of our knowledge. This knowledge is necessary for a full discussion of the role of response measurement and prediction in the proper exercise of good seamanship. Mathematical derivations have been purposely avoided.

The Sea

Swept by winds, pulled by gravity, and occasionally disturbed by some singular event such as an earthquake, the surface of the ocean presents an everchanging picture. It is the rare occurrence when the surface is completely calm, undisturbed by local or distant influences. The relationships between meteorology and oceanography have been the subject of extensive study. Oceanographers have attempted to develop statistical representations of the ocean surface based on vast (yet quite finite) amounts of data. Relatively simple concepts such as gravity wave theory have been extended (by the application of superposition) into the more realistic theories of irregular seas. The naval architect has been content to design to a specified design wave called the "trochoidal wave". The origin and acceptability of the trochoidal wave as a design parameter was quite pragmatic. It provided a satisfactory basis for conservatively built, standard ships. Large ships and platform-like marine structures have required that newer oceanographic concepts using spectral representations of the sea surface enter into the design. Hydrodynamics provided the tools for applying this relatively new knowledge while computer economics made the extensive numerical solutions possible.

The sailor uses the sea as a highway. He must reckon with its many moods. Unlike his predecessors who depended on the wind, the modern sailor has more room to compromise between distance and time. He has the option to elect head seas. Shipping of green water is now a more limiting phenomenon than it was in the days of sail. The sailor understands the sea based on his experiences. The intricasies of wave theory and the subtle differences in spectral definitions of the sea are not the province of the sailor. He has been shaped by the tradition of countless centuries of using the sea. The sailor eyes the pattern of the sea, he senses the motions of the deck. If it is time for a meal, he may alter course to provide a few minutes respite, appreciated by his fellow sailors as they precariously balance the soup bowls set before them.

There is one underlying fact which is common to the understandings of the oceanographer, hydrodynamicist, naval architect, and sailor: The ocean surface represents a state of energy. There is energy in the motion of the waves and the height of the tides. The energy has been transferred into the sea surface from atmospheric, terrestrial and lunar influences. The stronger and more persistent sources result in a wider spread of energy through the sea before it is attenuated. The swell patterns of distant storms have long been appreciated by sailors, but mathematical modeling of the phenomena has been a recent development. The euphemistic term "heavy weather damage" is the underwriters's acknowledgement of the energies of ocean waves. Water has mass and waves have motion. Elementary physics and energy concepts explain phenomena that sailors have coped with for ages.

The sea is composed of an infinite array of regular waves each having definitive characteristics such as wave length, period and amplitude. All of these wave patterns such as swells, seas, and local wind blown waves, are superimposed on each other to yield the random

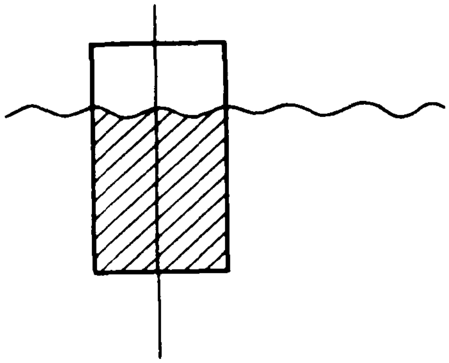


FIGURE 6. FLOATING IN CONTINUOUS TRAIN OF SMALL REGULAR WAVES.

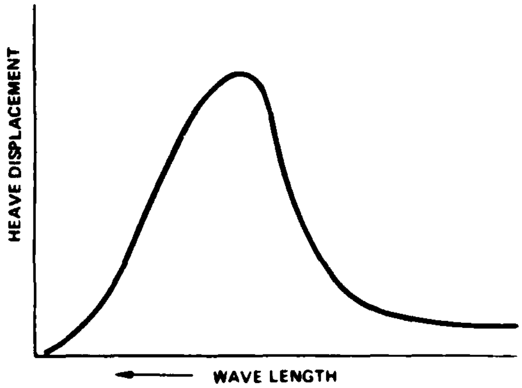


FIGURE 7. HEAVE RESPONSE CURVE

sea surface. One can select a particular characteristic, such as the wave length, and determine the energy present in that one wave train. It can be plotted as a point on a graph of energy versus wave characteristic. If the process is repeated for all the component waves, the resulting graph is called a spectral curve. Figure 2 shows a typical energy spectrum as the approximation of a limited number of components. The shape of the curve defines the energy distribution between the finite number of component waves. One can find the energy in any given wave component. The area under the curve is the total energy present. Let us assume that Figure 3 represents the spectrum which our observer derives for a 40 knot wind. If he repeats the process when the wind is 50 knots, 30 knots, and 20 knots, the resulting "family" of spectra might be represented as in Figure 4.

Wind duration, geography, water depth and many other factors can alter the spectral representation of the sea. If all the other factors were held constant but we moved our observer to a location where a land mass limited fetch (the distance over which the wind acts), the curves will be different. Suppose the wind shifts and opposes the already developed sea. Wave decay will be faster than if a wind maintained direction but died down. Oceanographers and meteorologists study these phenomena and then develop mathematical relationships to explain their knowledge. Observation periods are not limited to the short term but can be long term (over 50 years).

Sailors have intuitively understood this process. Man, the sailor, understood the need for seeking a harbor of safe refuge and the benefit for being in the lee of a shore centuries before; man, the scientist, attempted mathematically to model the phenomena. The sailor of old may not have understood mathematically defined energy concepts but he certainly feared the consequences of being dismasted and having timbers stove-in by the forces of the sea. It took real courage for him to depart from regions, where he knew the geography and locations of shelter, to sail on unknown seas.

The Ship

Early man, faced with the need to cross a body of water, probably paddled across with his hands using a log for flotation. Later, he found that a hollowed out log offered better protection. At some point, the body of water became larger. Man ventured with his craft onto waters that caused motion. He felt and saw the effect of waves. At first, he observed that his craft was suitable in some sea conditions and was helplessly tossed about in others. He learned that he could alter these responses. He could change course and adjust sail. The size and shape of his boat influenced his evaluation of what was an acceptable sea to sail on and what was not. He added outriggers, extended the sides, and finally went beyond the dugout into boats that he developed. He provided these craft with shapes that differed from the naturally occuring curves of the hollow log.

This evolutionary development provided the capability to sail successfully under a greater variety of sea conditions, but the advances had limits. The outrigger permitted tolerance of greater beam seas but it did not absolutely assure success. There were new concerns! The hollow log had been limited by motions; it could capsize. Craft constructed from components depended on the strength of the parts and the quality of construction. The additional stability of the outrigger could be completely negated if the lashings or transverse supports failed at sea. The size and shape of a constructed hull were of little consequence if the dimension and the quality of the planking could not withstand the pounding of the waves. Man's attempts to use the sea involved development of vessels or craft that responded to the energy in the sea. Each craft had motion responses and responses involving strength. There were limits which would result in loss of the craft if they were exceeded. Man gained experience from a particular craft and later, from classes of vessels. He appreciated the limits. Whenever possible, the sailor avoided the sea conditions which would imperil his vessel and threaten his own safety. Often he succeeded; many times he failed.

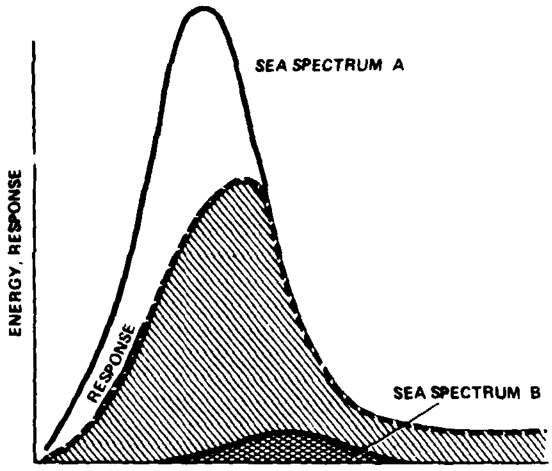


FIGURE 8. ENERGY AVAILABLE FOR TRANSFER TO A BUOY FROM DIFFERENT SEA CONDITION.

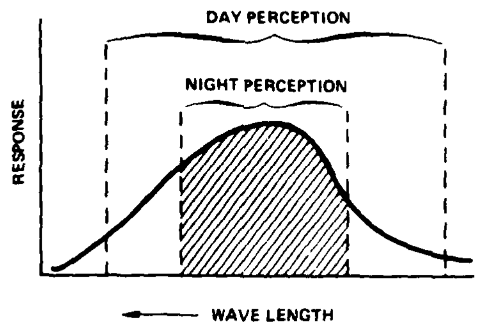


FIGURE 9. HEAVE RESPONSE SHOWING RANGE OF HUMAN DETECTION WITH AND WITHOUT VISUAL REFERENCE.

Let us consider the motion response of a buoy. In the static condition, Figure 5, its underwater volume displaces an amount of water equal to its own weight. If the water is still, the buoy has no motion. If we lift and drop the buoy, it will "bob up and down." Friction between the water and buoy will eventually dampen the oscillation and it will return to its resting state.

Suppose the surface of the water is disturbed by a continuous train of sinusoidal waves which have a single wave length that is much smaller than the dimensions of the buoy (Figure 6). It will not be noticeably influenced by these small waves. The inertia of the buoy and an entrapped "added mass" of water effectively cancel the energy in these waves. The bouy will respond to waves of greater wave length. The response at very long wave lengths is primarily hydrostatic - the buoy follows the surface elevation. This is illustrated in Figure 7 which defines the vertical heave response as a function of the wave length. The effects of added mass, damping, and hydrostatic forces describe the relationship of motion with respect to time (and thus to the passage of the waves). Large amplitude excursions will occur at resonance.

Recall how the spectral density curve of Figure 3 was developed. We can compare Figures 4 and 7. The greater the area shared under both curves the greater will be the response of the buoy in that sea condition. Figure 4 showed how sea spectra vary with meteorological and geographical conditions. We can now see graphically (Figure 8) how our buoy will change its heave response as sea conditions change. If the sea conditions are in the range of the natural frequency of the buoy the resultant heave response will be large. This is the basic explanation for the different responses that a 280,000 DWT tankship and a 10,500 DWT Victory ship will exhibit even when they are steaming at the same speed through the same sea conditions.

This description was deliberately brief. Many factors have been ignored. Clearly the buoy could respond in all six degrees of freedom. Each of these motions could be described separately in terms of acceleration, velocity, and displacement. Mathematical models have been developed which describe the events. Overall response is the mathematically summed result of the individual components.

So far, the discussion has been limited to motion responses. We cannot "see" stresses but there are distortions. It is doubtful that early sailors could see much distortion, with the exception of a split seam or a bent outrigger pole. In some modern ships distortions are visible. One can observe the twisting of the hull girder in a quartering sea. On very flexible ships one can observe the deflection in the hull and feel the deflections caused by higher frequency modes such as springing. In many cases, the responses are not measurable by the human senses but can be measured only with properly functioning equipment. The structural responses can be related to regular wave components. The influences of a given sea condition can be determined from the overlapping area of the spectral density curve with the transfer curve of the given response. The greater the area under the overlap, the greater the response.

The Sailor

The sailor is part of the system. The detection of a response has depended for ages on the sensing ability of human beings. This ability to sense responses is limited. Detection of translational and angular motions utilizes the equilibrium mechanism of the inner ear and the sensing of internal and external pressures. Generally, these mechanisms must be supported by visual references for reliable interpretation. The fluid movement in the inner ear can be misleading. Close your eyes, sit in a revolving chair and have someone spin the chair. You can sense the initial angular acceleration. Once the chair establishes a constant angular velocity, a sense of equilibrium returns. If the chair is

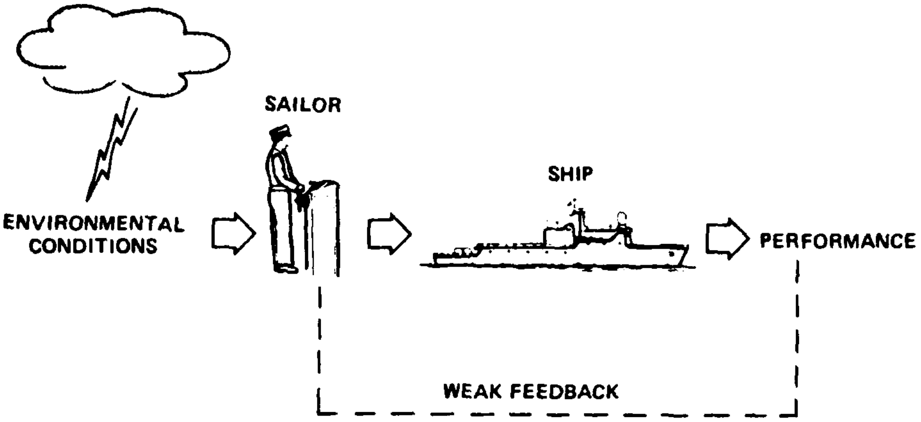


FIGURE 10. WEAK CLOSED LOOP SYSTEM

suddenly slowed or stopped, you would sense motion in the opposite direction. Repeat the experiment with open eyes. The visual sense will override the inner ear and you will observe the true condition.

A sailor could be placed on a moving platform at sea. His ability to detect various responses (accelerations, velocities, displacements) could be determined. We would find that there would be some lower and upper limit of detectable motion. This range of detection would be different for day and night. It would also be affected by his perspective of a fixed reference point (such as the distant horizon or a nearby wave staff). Figure 9 reproduces the heave response of our buoy which is now bounded by idealized limits of our on board human observer to detect the response both with and without visual cues. The observer will not detect the heave for the short wave lengths. The buoy will have a vertical motion but it will be below the threshold of detection by our observer. There will be a region of detectability with and without visual cues. Finally, for the very long wave length (such as tidal influences), unless there is a near visual cue, the human observer could not detect the change in elevation.

The System

A ship or other marine platform is a system. The sailor is the controller of that system. He can change some operating parameters such as course, speed, and the amount and distribution of mass. He can affect these changes in a variety of combinations. Figure 10 describes this system. The sailor can visually observe (at least in daylight hours) the environmental conditions. His visual observation can be supplemented by instrument values: wind speed and relative direction, barometric pressure, and temperature. He is influenced by his perception of changes in any of these cues. He considers the available information, applies his own experience, and makes decisions. His decisions are translated into manipulations of his ship. This could mean maintaining existing operating conditions, or changing one or more conditions. After implementing his decisions, he will observe the result in the performance of his ship. His observations of performance are limited to those which he can sense. Figure 10 shows that the situation is a weak feedback system. If his perception of the ship's performance doesn't indicate improvement, he may elect to try another change. This system has generally proven to be effective throughout time since most ships encountering rough weather are not lost.

Ships have over the past 20 years changed and so has the experience gained by the crew. For instance, locating the bridge aft is now almost a standard, isolating the sailor from the bow region where his perceptions often are much more highly stimulated. The master stays on the same ship for a shorter time than previously was the case, thus he gains less experience with the ship. Weather forecasts have become more frequent, cover larger areas and are generally more reliable. They warn the sailor of conditions that are coincident with rough weather, and the sailor is thus more likely to avoid severe storms. As a consequence, he has less experience from such situations. The level of experience at sea for masters has been declining.

The paradox in the situation is clear. Large capital intensive units carrying a cargo of often great hazard to the environment are required to keep tight schedules. They will be operated in rough weather by less experienced masters who are required to make decisions on safe and efficient operation based on their feelings of the wave

load level. Their feelings are considerably reduced due to the general increase in ship size and service speed.

When a ship is built and loaded, its motion and load carrying characteristics (called capability) are fixed. The sailor may influence the waveload situation (called demand) by changing speed and heading relative to the waves, Figure 11. The way this is done at sea is based on the sailor's feeling of the ship as learned through years of experience. He relates his senses to an unquantified level for the ship, its crew and cargo. But a ship is a large construction where noise, motion and sights are difficult to relate to safety levels. In addition, the loads are of a statistical nature which causes the master to react only when the return period between successive events (i.e. slamming, green sea, racing of propeller) is judged too short. That is, the event has often occurred before anything is done. This is a very crude measure which is evaluated differently from person to person and time to time.

The need to supplement the master's feel of the ship with measured values seems obvious. The significant (motion) response is a reliable measure of the load level and can be measured and displayed to the sailor (Lindemann and Nordenstrom 1975). However, this information must be adjusted to the ability of the sailor to interpret and act on the information correctly. A response monitoring instrument can provide information that can be used in conjunction with other information to sail a ship from one harbor to another.

Instrumentation which is sensitive and reliable can detect responses the sailor can not. Instrumentation can be used to back up his own observations. In Figure 12, the feedback loop is now semi-closed. There are still subjective uncertainties because we still do not know how far away we are from failure nor do we even know what the closest mode of failure is. The quality of response information has improved and the sailor can more confidently make his decision. He knows that he is altering conditions and has measurements of the relative changes. The sailor could be helped by additional knowledge. Prior experience on the reaction of his ship to similar changes he is considering will be useful. Alternately, he could make use of the mathematically derived seakeeping properties of his vessel. This information could be graphical or computer developed. Either experience or seakeeping predictions would improve the confidence of the sailor in predicting the result of his action.

However, in order to achieve this goal, the knowledge must be given to the sailor as a supplementary piece of information which he can use <u>when he needs it.</u> If a monitoring instrumentation excludes the sailors ability to relate the information to the overall picture, the result can be worse than before. The sailor can be given false security believing that the monitoring instrumentation will detect all possible oncoming hazards from the waves. Thus his alertness could be reduced and situations not sensed by the instrumentation may take him by surprise. These situations can be avoided if the sailor is given the command of the instrumentation and not vice versa.

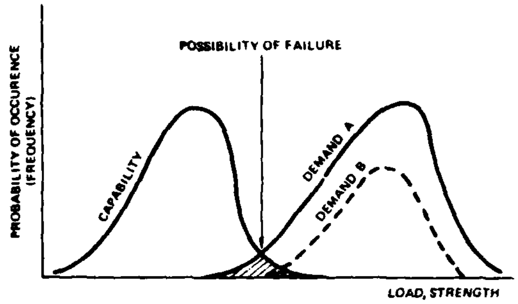


FIGURE 11. SHIP OPERATING CURVES.

The concept is simple. The ship will respond in various ways to the energy in the surface waves. The nature of this response will depend on the characteristics of the ship. The sailor utilizes all the available response information in conjunction with his assessment of the weather and sea to affect changes in order to safely bring his ship to port. This defines prudent seamanship.

IDENTIFICATION OF THE PROBLEM AREAS AND NEEDS

Improved ship safety is a meritorious goal for the entire maritime community. The term is often misused. In this context, we define it as minimizing the risk to life, property, or the marine environment during the conduct of maritime commerce. Methods that will reduce the frequency and extent of damage are desirable. A damaged ship may cause large environmental problems for society. This has been made clear during numerous recent accidents in which large oil spills damaged shorelines and endangered life. It is a major goal of the commercial maritime community to improve the economics of ship operation, to insure that cargoes are less exposed to damage as sailing time is reduced. Rising prices for bunker fuels have increased the importance of fuel economy to such an extent that it can represent the critical balance in ship operations economy. Better methods to decide vessel speed and course from a fuel economy point of view are desirable.

In order to tie together the concepts outlined in the above section, we have presented the problem areas and needs in a matrix form. There is little question that the technology to measure, process and display a real time analog of the dynamic response (midship bending stress or absolute motion) exists. However, is the technology sufficient to mitigate the problems; if so, how should it be used?

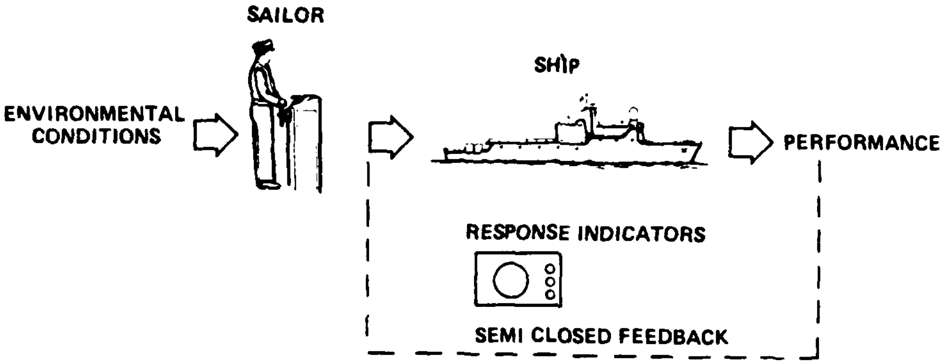


FIGURE 12. SEMI CLOSED LOOP SYSTEM

Difficulties arise when attempting to develop an instrument that can provide the master with meaningful information that is not misleading, is free from electronic and mechanical drift, and does not desensitize him to his ultimate responsibility for the safe and prudent operation of his vessel. Generally, when we refer to problem areas, our concern is focused on the safety of the vessel and crew. There are portions of the matrix that relate to needs that do not concern the safety of the vessel but are related to its management or operation. These needs are discussed here because we agree that the instrument may serve multiple purposes and indeed must serve to promote vessel operation economy if it is to become viable.

In the following paragraphs we will outline the items in the matrix, Table 1. The purpose is to provide the reader with an awareness of the problem areas and needs. Greater emphasis will be placed on what we believe to be the more significant research areas in a following section of the paper. The matrix has been divided into the four major sections that were outlined in the concept. The items within each of the major sections may be appropriate within another section but have been categorized into what we feel is the best major section. The "X" codes pertain to the level or degree that each item has been (or is being) addressed worldwide in the various research programs, summarized in Table 2, and discussed in the next section.

The Sea

Wave Input via Observations - The response instrumentation depends for performance of accurate predictions on a reasonably accurate definition of sea conditions. Human observations remain the most feasible method for assessing the enviroment in which the vessel is operating. Ships officers have some experience in making and recording observations. There is a large body of meteorological data based on this approach. "Observed" wave parameters can be expected to differ from "actual" conditions. The accuracy of response prediction depends primarily on the quality of the observation and thus on the skill of the observer.

Wave Input via On-Board Sensing - This may provide information to the master (or directly to the instrument) on the wave condition that the vessel is experiencing. One such device (Dalzell, 1978) measures the change in its distance from the water surface. This distance must be corrected to remove the motions of the ship and displayed as a significant wave height estimate. There are two systems being used for research on the Great Lakes bulk carrier STEWART J. CORT. A third syatem is under MarAd development and it is hoped that one of these may eventually be adapted for operational use.

Forecast Wave Data - Wave data forecasts from complex global math models (Cardone, 1973) can be used to plan voyage strategy. The U.S. Navy is pursuing this approach for naval vessels at the Fleet Numerical Weather Central (FNWC). The voyage strategy could be planned by the master in conjunction with or independently of a similar commercial service. This would be a natural evolution of the existing routing services. The Maritime Administration is actively pursuing such a development under its Ship Performance Program.

Environmental Input via Remote Sensing and Broadcast - Remote sensing can be achieved by two methods: satellite mounted radar altimeters or ocean buoys (NDBO). SEASAT-A radar devices were designed to determine the wave heights under the orbital track by measurement of the wave slope. The National Data Ocean Buoy measures waves, wind, water temperature and other environmental data, then transmits them via satellite to processing and broadcasting complexes on a routine basis. These data are utilized for broadcasts to mariners and stored for later processing for climatological study, but such data are only available for the specific buoy locations.

The Ship

Structured Instruction in Vessel Response and Loadings - Training of ships' officers in the operations of the instrument will require more than learning how to start it up or to shift from one display mode to another. It will require a structured course on the fundementals of vessel response to its loadings, which can best be learned in a classroom environment. The course work would be more complex than that taught to deck officers in a radar school. Although deck officers at the various schools are currently introduced to the fundementals of naval architecture this must be augmented by a basic consideration of ship motions and loadings. The (Norwegian) S03 project has considered this a key element of the overall program. Some of the topics of the textbook/course notes are:

* Part 1 deals with general ship knowledge, weather and fascimile and heavy weather damage experience
* Part 2 discusses statistics, wave/weather interaction, abnormal wave conditions and wave forecasting. The relationship between wave-induced motions and loads, weather, speed and course are followed by a dicussion of the analytical models and their limitations
* Part 3 presents specific examples of motions for different ship types, with emphasis on the wave length effects as illustrated in their simple guidance charts.

Still Water (Long Term) Stress Variations - These stress variations, which can include *diurnal and seasonal changes as well as the* normal alteration of loading as fuel and stores are consumed and ballast is added, have not received a great deal of research attention. They certainly exist (Dalzell, 1979). The empirical base of the classification society rules compensates for these variations. Evaluating the still water variations is important because they are a significant component of the total hull girder loading.

Long Term Data Base for Design Purposes - With the routine log entry of the observed sea conditions, the instrument can serve as a passive data collection system. Heretofore, such data collection efforts have been undertaken through dedicated research programs. These instruments could serve in this capacity as a side benefit. The instrumentation could thus be used to provide a broad data base to support evaluation of existing scantling requirements. The various worldwide individual data collection programs such as those carried out by the Ship Structure Committee in the United States have led to more efficient structures (Chazal, et al, 1975). Current design requirements for larger vessels are based on the improved understanding of ship response. It is doubtful that these vessels would have been possible if the designs were predicated on simple extrapolations of the section modulus requirements for existing smaller ships. The structural configurations would have been infeasible. Improving the data base could lead to further design efficiencies.

Scantlings Reduction - There may be a temptation to suggest that the mere presence of response instrumentation would support scantling reduction on the equipped ships. This would be similar to the present practice of the corrosion allowance under certain conditions. The authors urge extreme caution because the present state of the technology does not permit such an exact evaluation of the failure points for a complex ship structure. Even if an exact evaluation were possible, allowance must be made for malfunctions of the instrumentation system.

Voyage Recorder - The National Transportation Safety Board (NTSB) has recommended that a voyage recorder similar to a flight recorder be required on ships to assist in analyzing casualties. The response instrumentation could be modified to provide for a recoverable capsule. Some technical effort is required to develop the specifications for such a device. The merits of this proposal must be balanced against the potential use of the information in any form of punitive proceeding against the master. The aviation experience with flight recorders should be studied carefully so that proper legal safeguards are provided.

Fracture/Fatigue Control - Fracture control concepts which include fatigue considerations can be tied to a better definition of the loading history of the structure. Exact predictions of failure in the case of complex structures are not possible and may never be achieved. It is certainly feasible to consider the load history in a relative sense to estimate the remaining useful life of the ship. Adjustments could be made to the inspection schedule to keep a ship in service by monitoring and correcting localized failures. This occurs today on the basis of chronological age which is a less reliable parameter.

The Sailor

Elementary Instrument - In the simplest version, an instrument will provide a needle that oscillates and displays an instantaneous value for bending stress or accelerations. The components of this instrument are:

* accelerometer (usually located at the bow), or
* electrical strain gage (usually located at midships)
* signal conditioner
* meter

Instruments of this type have been installed on Great Lakes bulk carriers for a number of years (Lewis, et al 1979). This device can be contained in the meter cabinet and provide the master with a weighted average, called a RMS (Root Mean Square). The oscillating gage allows him to associate certain vessel distortions with, for example, vertical bending stresses. This instrument does not have any means for recording or displaying the history of the loads. It does not discriminate between sources of load or the causes for stress. The dissemination of the information is left entirely within the master's memory. If the sensor is a strain gage, the instrument can be used as an indicator of the still water bending stress, since the stress can be read during loading or ballasting operations.

REVISED

Table 1

Problem Areas Investigated and Needs Matrix

Areas and Needs	Research Program Area (See Table 2) 1	2	3	4	5	6	7	State of the Technology
The Sea								
Wave input via observations	X	X	X	X	X	X	X	Near Term Solution Possible
Wave input via on-board sensing								Near Term Solution Possible
Wave forecast data			X	X			X	Research Needed
Wave input via remote sensing							X	Research Needed
The Ship								
Structured instruction in vessel response and loadings		X		X	X			Near Term Solution Possible
Still water (long term) stress variations			X		X			Satisfactory
Long term data base collection	X	X	X	X	X	X	X	Satisfactory
Scantlings reduction								Satisfactory
Voyage recorder								Near Term Solution Possible
Fracture/fatigue control								Near Term Solution Possible
The Sailor								
Elementary instrument	X	X				X		Satisfactory
Simplified/complex display		X			X			Near Term Solution Possible
Human factors	X	X		X	X			Research Needed
Human engineering of display/interaction		X	X	X	X	X	X	Near Term Solution Possible
Location and extent of display		X	X	X	X	X	X	Near Term Solution Possible
Separation of low and high frequency	X	X	X	X	X			Near Term Solution Possible
Computer decisions						X		Satisfactory
Training of ships' officers		X						Near Term Solution Possible
Loading calculator	X		X		X		X	Satisfactory
Still water loading calculator differences			X		X			Near Term Solution Possible
Administration/management use					X			Near Term Solution Possible
Improper use of limits to control schedule								Satisfactory
The System/Instrumentation								
Alerts		X	X	X	X	X	X	Research Needed
Pressure to use system for warning								Satisfactory
Instrument reliability	X	X	X	X	X	X	X	Near Term Solution Possible
Instrument diagnosis		X						Near Term Solution Possible
Number of sensors (redundancy)					X			Near Term Solution Possible
Sensitivity to vessel size		X			X	X		Research Needed
Cargo damage reduction	X	X	X	X		X	X	Near Term Solution Possible
Springing response prediction					X			Research Needed
Prediction of combined response			X	X	X		X	Research Needed
Wave-induced response prediction		X	X	X	X		X	Research Needed
Slam/green water detection/prediction	X	X	X	X		X		Near Term Solution Possible
Dynamic stability prediction		X						Research Needed
Maneuvering display/prediction								Research Needed
Location of strain gages/sensors		X	X		X	X		Near Term Solution Possible

Table 2

Summary of Previous and Current Research Programs

	Research Program	Research Begun	Vessel Type	Type of Instrument
	Taylor Model Basin Flexing Stress Monitor	1961	Destroyer	Analog
	Lockheed Stress Warning	1973	Container	
1	Brown Brothers Slamming Indicator	1969		
	Mitsui Navigation Monitor	1975		Analog
	AMERICAN AQUARIUS - MarAd, U.S.Lines	1975	Container	Digital
2	SO3 - NTNF, Det norske Veritas	1970	Ro/Ro	
3	LASH ITALIA - NMRC, Prudential Lines	1972	LASH	
4	FURMAN - NMRC, Military Sealift Command	1977	Cargo	
5	BURNS HARBOR - MarAd, Bethlehem Steel	1977	Bulk	
6	HOLLANDIA - Lloyd's, Netherlands Maritime	1977	Container	
7	HELM - Hoffman	1977	Crane Ship	Digital

<u>Simplified/Complex Display</u> - The wave environment that the ship operates in is random in nature. That means that to obtain accurate results we must average a number of values, or use statistics, in much the same way that a ship's officer observes the state of the sea by averaging many waves. For the response instrument to make these computations, the large storage and calculation capacity of a DIGITAL computer is required. One problem with introducing a computer is that it becomes much too easy to display excessive and unusable data. The advantage of a computer based instrument (which all the current research programs utilize) is that not only can it be programmed for a display that can be recognized and understood only by naval achitects, but it can also be programmed with easily understood and meaningful displays useful to the master in forming and executing his voyage strategy. Achieving the latter without losing the data for the former is a useful goal.

<u>Human Factors</u> - It is important that the master be given enough information to sail his vessel safely and efficiently. His senses must not be occupied with information that is not useful. Careful study of the interaction of the master and the instrument must be pursued. Consideration must be given to the abilities of each ship's officer when implementing the instrument in the "system". The instrument must be designed for his use, not for his deciphering.

<u>Human Engineering of the Display/Interaction</u> - A display that is cluttered with too many numbers or too much information stands very little chance of being accepted by ship's officers. The displays must be designed to present information in a quasi-familiar manner. For example, a simple display of the vertical accelerations at the bow might be represented by a vertical display, or a record of the envelope of bending stress might be a set of horizontal stars which portray the envelope of extremes over the last twenty minutes. Again, one can recognize the advantage of a digital computer for ease in changing display formats. The utility of the controls will make the interaction most acceptable. Early versions of these instruments have required the master to execute a complicated set of "computer" instructions to run a display or obtain a print out. These are easy for computer-oriented naval architects but roadblocks for the uninitiated. Methods to enhance the instrument include the use of single keys to command a display and a bank of rotary switches for value selection rather than keying in each number separately.

<u>Location and Extent of Display</u> - The location of the instrument display should be directly related to its utilization in a particular aspect of ship operations. The display should be in the pilothouse and accessible for reference in shiphandling situations. Display and ease of operation are important. The keyboard used to communicate with the computer should not be placed in the pilothouse but in another location where it can be used by the chief mate for preloading of his vessel, or by other officers for the administrative functions described below.

<u>Separation and Display of High and Low Frequencies</u> - As a vessel works in heavy seas it is distorting and flexing, and heaving and pitching. The pitching of the vessel creates a low frequency bending movement, while the distortions that occur following slamming, called whipping, creates a dynamic vibratory stress denoted by its high frequency. Great Lakes bulk carriers (Chen, et al,1977) and the largest oceangoing tank vessels experience another high frequency stress called springing. In these

vessels, the relative magnitude of the springing stress is considerably greater than the whipping stress. In either case, however, the master must know which type of stress is primarily responsible for the loading on his vessel, because the corrective action for the one will probably exacerbate the other. It is difficult to explain here and hard to portray in a display without confusion.

Computer Decisions - In the extreme, there is the potential that computerized decision making could be incorporated which would bypass the human evaluation. The control system for that process is possible today. The state of knowledge in the foreseeable future does not allow such a complex analysis to be reduced to computer coding. Human judgement and responsiblity will remain the best overall guarantor of ship safety and operational efficiency for many years to come.

Training of Ships' Officers - The training of masters and mates to use new instruments and devices must be considered; recall the analogy of the introduction of radar. The potential and limitations of any device must be assessed by the deck officers themselves. The nature of the instrument is to monitor and display information on the loading on their vessel during heavy weather. Since extreme conditions occur with generally low probability there may be a need to use simulation techniques for training.

Loading Calculator - The software for a loading calculator can be easily incorporated in the digital computer package. This cannot serve as a replacement for the loading manual but once the deck officer is confident of its operation, it can speed his somewhat lengthy computations considerably. The still water calculator is a basic useful introduction for the ship's officer to familiarize him with the functions of the equipment.

Still Water Loading Calculator Differences - Stillwater stress values can vary for a number of reasons besides the distribution of various dead loads. This has been broadly discussed in a prior section. The ship's officer must understand why the calculated value will probably differ from the instrument value. Both can differ from the unknown "actual" value. In a relative sense the stillwater loads are controlled through proper weight distrubution and the dynamic or motion induced loads are controlled through proper shiphandling.

Administration and Management Information - Auxiliary uses for a powerful mini-computer are nearly limitless. They might include time-keeping, payroll and leave functions, supply inventory and ordering, and training curriculae. These functions would of course be operated in a secondary capacity to the major functions: analysis and display of stresses and accelerations and data collection.

Improper Use of the Programmable "Limits" by Planning Personnel to Control Vessel Schedule and Operation - Involvement of financial managers in the control of the vessel could color the judgement of the master. Fewer vessels to command and larger number of masters could encourage masters to take chances they might not normally take. We realize that the shipping company executive does not want to lose a vessel but his understanding of the limited basis for "limits" and mechanisms of failure may create an uncomfortable situation for the master. Perhaps some restrictions should be made on data retrieval, storage and subsequent uses.

The System/Instrumentation

Alerts - Although intended to aid the master in the safe operation of his ship, if arbitrarily set without direct operational significance to the master's normal decision-making, they may tend to desensitize his awareness of other important responses of his vessel. Further, if they are not operational meaningful, they will most likely be ignored. Establishment of the levels can have tremendous implications for safety and economy. So far, no well defined limits have been set based on the possiblity of damage. Some ideas on setting levels have been reported (Lindemann, 1977), but the general attitude is that these limits are not absolute and are only recommended as an indication for growing concern. At present, one is unable to give an absolutely defined response that should be decisive for the master's actions.

Pressure to Use Instrument as a Warning Device - To help make the instrument more attractive from an economic standpoint, there could be continuous pressure for its use as a "blinking red light." Some may believe that such a limit will guarantee safe operation but Admiral Nimitz's quote at the lead in for this paper is still appropriate and should put this in perspective.

Instrument Reliability - The proper functioning of the response instrument requires that each component within that instrument also perform reliably. Strain gages have not performed completely satisfactorily, being subject to mechanical and electrical drift. These difficulties, as well as the costs for cabling and redundant gages, have been problem areas in all the research programs. The S03 program has attempted to eliminate the use of strain gages in their instruments relying solely on motions response measurement. Accelerometers are less prone to drift and failure but their sensitivity, potential frequency response problems and short life reduce the reliability of the entire response instrument. Equipment failures have continuously disappointed the masters and officers charged with trying to use electronic instruments for productive work on their vessels. We call attention to the problems associated with keeping radar sets operational. A critical analysis of the MTBF (mean time between failures) is necessary as well as establishment of a reliability design goal. There have long been serious questions as to the reliabiliity of electronic equipment in the marine environment.

Instrument Diagnosis - In order to ascertain that the intrument is functioning correctly, a method of diagnosis or checkout must be employed. It may be self initated each hour (or day) or it may be performed by the officer on watch. There must also be a variety of routines employed for the validation of each module or subsystem. Notification of the ship's officer that some component is malfunctioning is necessary so that erroneous information is not used in the ship maneuvering strategy.

Number of Strain Gages (Sensors) - In the extreme, an instrument might be assembled with only one strain gage or accelerometer. (A reliability design goal would immediately preclude this occurrence.) A local failure near the single strain gage could reduce the stresses that the gage measures, thus providing the master with incorrect data and with no means to verify or validate its readings.

Sensitivity to Vessel Size - The ship's officer in command of a small cargo vessel has a much greater sense of "feel" than does the same officer on a ULCC. Other factors influence his "feel" for the vessel, especially the location of the pilothouse. In the cargo ship which is pitching and heaving severely and where the hull girder is experiencing heavy loading, the officer is well aware of the loading his vessel is taking. The ULCC may be experiencing similarly heavy loading, but to the ship's officer there is no sense of "feel" due to less severe pitch and heave. In following seas the slow motions response of both vessels do not relate to the loading on the hull girder, which can be as severe as in the head seas condition.

Cargo Damage Reduction - On certain ships (Ro-Ro, container, barge -carrying) it is desirable to know if the lashings are sufficient for the motions experienced. Such an evaluation can be obtained based on measured motions combined with input on the masses in question and their lashings. This procedure will require individually formulated cases which could be too complicated to model correctly. There exists a possible solution to this problem using general evaluations of the inertia forces for assumed standard masses.

Springing (Vibratory) Response Prediction - Once the response instrumentation package includes a digital computer, the naval architect sees his opportunity to incorporate predictions. This is usually in the form of guidance figures or computations that indicate what reduction in the loads or motions would be achieved with certain changes in sailing strategy. The obvious, and correct variables are vessel speed and heading. The vibratory distortion of the hull girder which is primarily caused by buoyancy variations of short steep waves is of great concern to the Great Lakes bulk carrier fleet. Springing stresses on oceangoing tank vessels are believed to reach the same levels as whipping stresses in high speed cargo vessels (Gran, 1976).

Prediction of Combined Dynamic Responses - In order to predict the combined (wave-induced and springing) stresses, accurate prediction of the method of combination of the two must be known. This is not of great importance for oceangoing vessels but is of the major importance for Great Lakes bulk carriers.

Wave-Induced Response Prediction - The prediction of the low-frequency (referred to as wave-induced) loading is necessary for ocean and Great Lakes vessels. Considerable research and validation of theory has been underway for over thirty years.

Slam/Green Water Detection and Prediction - It is difficult to perceive the severity of slamming or green seas especially on ships with the bridge aft. The severity can, however, be evaluated indirectly by measurement of the high frequency (whipping) stresses induced in the hull girder by the slam. The reader will recall from the previous paragraphs that springing stresses, induced by short waves, contribute to the high frequency component. If the ship is experiencing both the whipping and springing stress, separation of the two components is nearly impossible. However, no data exist which suggests this a serious problem. Measurement of the bow accelerations, filtering of the high and low frequency components and display of the high frequency component will provide the same information as well as the same detection problem as discussed above. An alternative method to detect slam and green seas is to strain gage a shell frame in the bow flare and measure the stresses.

Dynamic Stability Predictions - The Analysis of Stability in waves is a complex problem and no adequate analysis technique is available at the present time. Early studies with models in open water (Paulling, 1975) have led to the proposal of analytical models. Verification using conventional model tests are underway. The righting arm curve for a hull in a standing wave will change substantially. A wave of length 130 m will travel at a velocity of approximately 27.5 knots which is of the order of the service speed of fast containerships. If a ship sailing at full speed experiences heavy following sea swells, the wave may be fairly stable relative to the ship and thus significantly change the characteristic of the still water righting arm curve. With a crest at midships, the stability will be endangered. The problems of dynamic stability were previously believed to be of greatest importance for smaller ships, i.e. fishing vessels, but recent events and operational experience suggest a more critical review is necessary.

Maneuvering Display and Prediction - None of the current research programs includes maneuvering as a response parameter. We note that maneuvering data is the first of the response parameters which was mandated to be provided to masters and pilots. The intent was to aid in their prediction of the ship's capabilities when navigating in confined waters. The requirements recognize limitations on the accuracy of the data, especially as vessel and channel conditions change. Maneuvering parameters are a natural extension of the capability of any response prediction device. The prediction of maneuvering parameters is a very complex process that is not well understood. There are ongoing programs to collect response data to improve maneuvering prediction capability. These efforts are independent of the seakeeping programs discussed in this paper. There are sound reasons for maintaining research independence. The common features of each concept will eventually bring

them together. Economies that are not possible at a basic research stage can be achieved at the application stage.

Location of Strain Gages/Sensors - The selection of the location for the sensors must be carefully considered. The location should be such that they sense the most meaningful hull girder response, including still water bending, torsion, wave-induced bending and wave-induced vibratory stresses, roll, vertical and lateral accelerations.

A CRITICAL ASSESSMENT OF THE STATE OF THE TECHNOLOGY

The preceeding overview section did not discuss any problem area in great depth. Table 1 includes a final column entitled "State of the Technology" with a description of the authors' opinion on each technical area. The state of the technology is based on our perception of the adequacy of the present level of knowledge needed to establish specifications for response instrumentation and prediction equipment. It is possible that an item marked "satisfactory" still could need extensive research. The authors feel that such an effort may not produce a significant improvement in the proposed application. In the interest of brevity, problem areas marked "satisfactory" or "near future solution" will not be discussed further. The authors recognize that others may not share these same opinions on the adequacy of the existing technology base.

The areas marked "needs research" will be discussed within this section. There is a substantial need to pursue the development of a deeper understanding in these problem areas because of their impact on the utility of the overall concept.

The Sea

Wave Forecast Data - Considerably more development of wave forecast models is necessary to reduce the present limitations of the techniques especially near land masses and high intensity storms.

Wave Input via Remote Sensing - The SEASAT-A satellite is no longer operational and there are no immediate plans for another unit to be launched. Further, the techniques employed for data acquistion require extensive validation and verification. Means for management of the enormous data base produced (Oakley, 1979) and broadcast of wave and wind data pertinent to the mariner is yet to be addressed. Although the ocean buoy (NDBO) data do not hold the same potential for aiding the master with his voyage strategy planning, they do provide excellent environmental data, though limited to specific locations. Broadcast to ships of wave data via advanced communications systems like MARISAT is feasible for use with response instrumentation, but of limited value due to modelling difficultties.

The Sailor

Human Factors - The level of ship response information that can be assimilated by a master must be better understood, and will increase as each master gains experience using the types of information that can be provided by these instruments. Because masters have varied backgrounds and experience there will always remain differences in their abilities. The future development of these instruments will probably reflect this. Retention of command by the master will remain a primary issue in the implementation of each instrument and thus emphasis on guidence, or advisory information display will be important in future developments.

The System/Instrumentation

Alerts - There has been a considerable impetus given to development of equipment which could alert the master to an incipient failure in his ship (NSTB, TEXACO OKLAHOMA). This seems to be an idealistic goal which may be most difficult to attain. The complexities of ship structure and its response in the ocean environment makes prediction of an absolute failure level beyond present capabilities.

There may also be a problem of desensitizing the human operator by the presence of an alert. Aircraft accidents involving flight into the ground have occurred in spite of the presence of Ground Proximity Warning Alerts in the cockpit. On the other hand there has been a measurable reduction in the overall statistics of air carrier accidents in this category since the Ground Proximity Warning indicators were required. In any event the measurement of an approach to failure on a ship is far more complex than the vertical distance measurement between an aircraft and the ground.

In the ideal situation an alert could be established based on the occurrence of some event, such as a stress or acceleration level, and an estimate of the capacity of the ship or its cargo to accept additional loading before damage. At the present time the estimation of any such level would be arbitrary and would be meaningless. For example, if an alert was established for midship bending stress it could be possible to induce a casualty through some other mode of hull failure if one were to become a slave to that single stress alert.

At the present time the more practical approach would be to establish no arbitrary level for alerts, but to allow masters to continue to make their decisions based on their experience while maintaining a history of their actions in given situations. Then, over a period of time and using a broad sample of ships' officers actions, one could deduce the level at which "prudent seamanship" indicates corrective action should be taken. This measure of prudent seamanship would not indicate an onset of a catastrophe, but simply suggest to a master that in the collective judgement of his peers the parameter of interest should be of concern to him. He would be alerted to take care but not so threatened with impending disaster that he would

be induced to take foolish action. The more probable result would be heightening of his awareness and application of his judgement to the situation. This is the approach which the Norwegian effort has taken in recent years. Patterns have emerged (Lindemann 1979).

Since prudent seamanship is an implied consideration of classification requirements it seems reasonable that the problem of setting an alert be addressed in this fashion. The setting of an alert has important ramifications which must be studied. There are questions we can not answer at this time nor do we anticipate present studies to answer. It is the authors' collective opinion that ALERTS SHOULD NOT BE SET for purposes of failure prediction. Further to emphasize this point: the master of the vessel knows when he is in heavy weather. The primary purpose of the monitoring instrument is to provide him with reliable information on the "quantitative level of stress or other response" his vessel is experiencing, since he can not see or feel the response.

On the other hand, the instrument can be fitted with an adjustable alert capability. The setting of such an alert by the master can aid him in calibration of ship response severity. By so doing, the master has the option to leave quantitative instructions to the officer of the watch which can be more consistantly followed, and the master's conduct of shiphandling can be more effective and productive.

Sensitivity to Vessel Size - The research programs have generally been based on the instrumentation of moderate sized, highly motions sensitive cargo vessels. Better answers to the questions of which type of sensor (strain gage, accelerometer or roll gyro) and how many can only be obtained through analysis of many ship years of experience on different trade routes. Additional vessels to cover the range of merchant ships must include as a minimum:

* VLCC or ULCC
* Large, high speed containership (SL-7, ACT)
* LNG carriers (125,000 cubic meters or above)
* Semi-submersible drilling unit

Springing Response Predictions - Springing (vibratory) stresses are of concern on Great Lakes bulk carriers but are believed to be of less importance on oceangoing bulk cargo vessels (Gran,1976). The severity of these stresses can be evaluated by filtering out the wave-induced component and displaying the results. The present knowledge of springing is insufficient for reliable predictions. In general, speed reduction and heading changes are known to modify the excitation of springing responses and can be used as measures to reduce the level of springing. Springing research is new in camparison to thirty years and billions of dollars devoted to understanding low frequency dynamic (wave-induced) loading of the hull girder. vanGunsteren (1978) has summarized the early research in a most complete and readable manner. Theoretical, model and analytical work has been conducted by Faltinsen (1979) at Trondheim. Current research sponsored by the American Bureau of Shipping and the Maritime Administration includes extensive model testing and basic hydrodynamic development at the University of Michigan (Troesch, 1980). Although hydrodynamicists are aided by the extensive research programs on wave-induced loadings, considerable expenditures of human and financial resources will be needed before predictions will be possible at the same confidence level.

Prediction of Combined Dynamic Response - The prediction of the manner in which high (springing, whipping) and low (wave-induced) frequency responses combine is essential for guidance when these instruments are implemented on Great Lakes bulk carriers. The reason for this is the high level of the springing response in these large vessels. The theorectical basis is inadequate. Full scale research is underway using the STEWART J. CORT, while theoretical efforts are being sponsored by the American Bureau of shipping and the Coast Guard. These efforts are concentrating on analyses on the time domain, and may have far reaching application for study of bow flare slamming and other transient loadings experienced by containerships. In the meantime, the filtering of hull stresses into still water and low and high frequency component allows their analysis and assessment.

Wave Induced Response Predictions - Guidance information on wave-induced response levels can be used by the master to decide on changes in speed and course to alter the various response levels. Responses are assumed to be linearly dependent on wave height; this has been found to be sufficiently accurate for responses such as heave and pitch, at least for moderate forward speeds. This means that the significant response magnitude is proportional to the significant (similar to observed) wave height. Guidance information can be used to improve ship safety by indicating the effect a change in speed or course can have on responses. Since all such data have only statistical meaning, the information will not yield precise values of the percentage change in response levels.

Advanced guidance information on the choice of optimum speed and course is an economically attractive prospect. However, in order to carry out such an analysis, the ship's added resistance in waves must be known. Although long recognized by the mariner as a result of deceleration of the vessel as it plows into heavy seas, added resistance is but little understood by naval architects, as they attempt to develop mathmatical models to describe its effect. An assessment of the technology is given by (Salvesen, 1978). Existing methods are believed to give comparable results when the scatter in experimental data is taken into consideration. For such analysis a fairly accurate estimate of the wave spectrum is needed, and existing techniques do not seem to yield accurate estimates. Criteria for voluntary speed reduction in heavy weather are not well defined. However, some data are available linking voluntary speed reduction to vertical acceleration and slamming frequencies (Aertssen, 1968). An extensive application of these criteria must be carefully evaluated before being put to practical use. The technology level does not provide data of sufficient accuracy; power-fuel analyses are expected to yield results of questionable value. On-board weather routing needs, in addition to knowledge of added resistance, to apply criteria for voluntary speed reduction and reliable forecasts of wave conditions (wave energy spectrum) for the oncoming time period (24-72 hours). Forecasts of

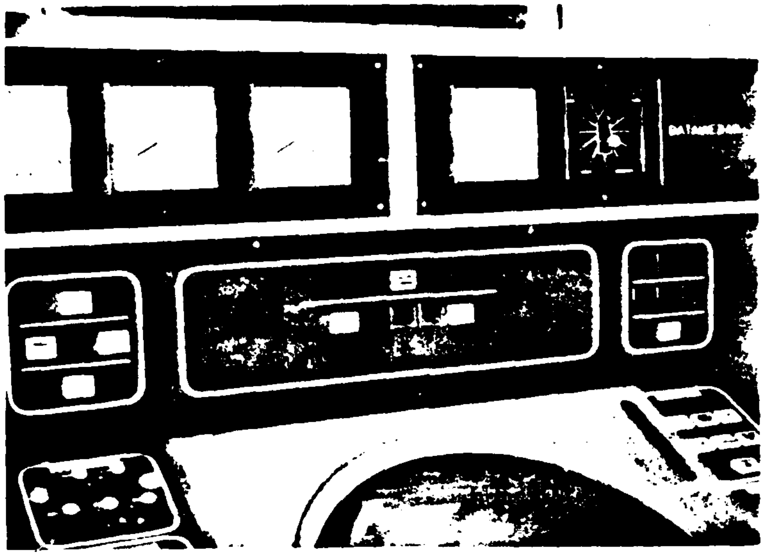


FIGURE 13. PHOTOGRAPH SHOWING SO3 INSTALLATION ON RO/RO VESSEL

wave spectra, though not generally available, are being produced regularly by the FNWC and used by commercial forecasting services in the U.S. It is believed that implementation of this forecast technology with response monitoring instrumentation requires significant experimental efforts before its utility can be established.

Maneuvering Display and Prediction- Discussion of research needs in this area are not within the scope of this paper. It is the authors' opinion that advantageous use of the computational and storage abilities of the computer-based instrument could be made.

DEVELOPMENT PROGRAMS

Analytical studies, experimental installations and instrumentation development have been underway since the early 1960s in the United States, Norway, England, the Netherlands and Japan. Table 2 provides a summary of the development programs along with some pertinent information for the reader. The early programs (number 1) and the current programs (numbers 2 through 7) are referenced in Table 1 to indicate technical areas included in each program. A column provides the approximate date the program was begun. It is interesting to note that the availability of inexpensive, powerful mini-computers had a significant impact on the recent programs. The early programs will only be briefly summarized. The SO3, ITALIA, FURMAN and BURNS HARBOR are under study by the authors and will be presented in more detail. The HOLLANDIA, being conducted by Lloyd's and the Netherlands Maritime Institute, and the HELM, a U.S. effort that has gained considerable use in North Sea heavy lift operations, will also be discussed.

Each of these programs has contributed to increasing the state of technology. The cooperation of individual ship officers, naval architects, companies and agencies must be acknowledged.

The Early Programs

The early research programs, primarily response monitoring, were summarized under National Maritime Research Center (NMRC) sponsorship by Carleton and Winton (1975) and Hoffman and Lewis (1976). These reports evaluated each instrument on the basis of eleven parameters, including: responses considered, sensors, displays, alarms, guidance, reliability and cost. These early programs were:

- The Taylor Model Basin Flexing Stress Monitor, developed and tested in 1961.
- The Lockheed Stress Warning System, developed in 1973 but had a poor operating history in terms of reliability.
- The Brown Brothers Bow Slamming Indication Equipment, included means for determining bow emergence as well as plate deflections. This was a cooperative effort between the National Physical Laboratory and Manchester Liners Inc.
- The Mitsui Navigation Monitor System, a simple predictive instrument as well as an active strain monitor.
- The AMERICAN AQUARIUS, sponsored by the U.S. Maritime Administration (MarAd) and installed with the cooperation of the U.S. Lines on a LANCER class container ship. The instrument included stability and damage assessments as well as stress and slamming measurements. The instrument onboard the AQUARIUS provided only monitoring capability with alert level indications. No simulation of ship responses was included and thus no guidance information was produced for assessing the consequences of an action or a change in environmental conditions.

The SO3 Project

In Norway, Det norske Veritas (DnV) took actions in 1970 to establish a research program that could provide the master with an instrument capable of analyzing the wave loads on the hull. Hydrodynamic theories and the knowledge of the statistical nature of the wave loads, together with current computer technology, had increased the possibilities for a successful effort. From this knowledge and their growing concern for the problems experienced by desensitized masters when navigating supertankers in heavy weather, Det norske Veritas put forward the idea of providing an instrument on the bridge that was capable of indicating to the master the loads experienced by his ship. It was hoped that a better understanding of the influence of waves on the ship would increase the level of operating safety. The idea gained support from the Norwegian shipping industry. Plans were prepared and resulted in the formal organization of the Hull Surveillance Projects (Skrogovervaking: SO Projects) in 1971.

The loss of ANITA and NORSE VARIANT with 61 lives in heavy weather off Nova Scotia in March 1973 resulted in a serious commitment in project activities from the Norwegian Maritime Directorate. They foresaw the possibilities to reduce heavy weather hazards by providing better information to the master and thus put him in a position to make a more objective evaluation of the wave forces.

The first contact was established with the ship-owner, Wilh. Wilhelmsen, who sought improvements in their fleet's efficiency. This joint effort to establish a research program gained support from the Norwegian Royal Council for Scientific and Industrial Research (NTNF). By 1971, the SO1 (Hull Surveillance 1) project was formally organized. Full scale investigations of wave-induced motions and loads on M/S TAIMYR resulted in a recommended Hull Surveillance *Instrument* capable of monitoring the ship's global safety (Lindemann, 1975). The instrument was produced and installed on ten ships, providing more than 20 ship-years of experience. This full scale trial program, the SO2-project, was successfully completed (Lindemann and Nordenstrom) in 1975.

In 1976 the SO3 project evolved with the objective to develop the Hull Surveillance System into an instrument (Figure 13) that could provide guidance in addition to the monitoring function. It was felt that an effort should be made to utilize the current technology (where reliable results could be expected) by aiding the master in choosing his sailing strategy. This would include on board weather routing, trend analysis and monitored stability. In addition to the need for improved instrumentation, the deck officers'general knowledge of a ship's seakeeping characteristics was found to be inadequate. Improved seakeeping knowledge would enable the master to better evaluate the ship's condition and take advantage of a response measuring aid. Hence the SO3 project sponsored the development of teaching aids for maritime education. This part of the SO3 project will not be treated in this paper other than listing the course/text

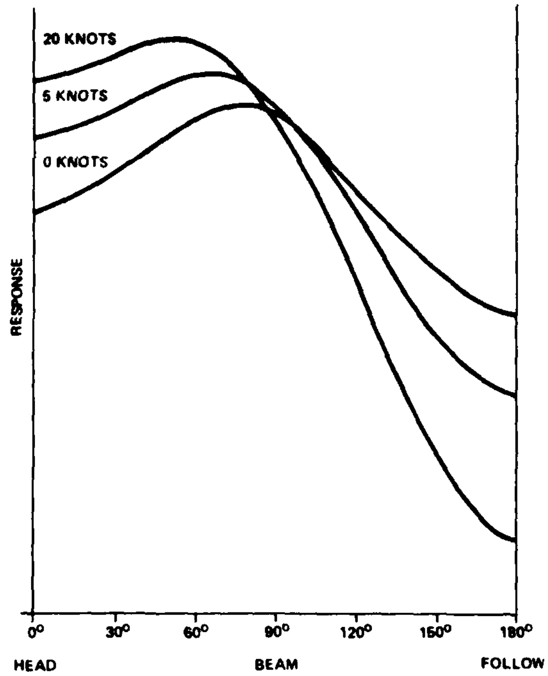


FIGURE 14. VERTICAL ACCELERATION OF THE BOW.

outline in a previous section. The SO3 Hull Surveillance Instrument currently being evaluated in full scale trials consists of six major modules:

* Condition Monitoring - This module displays the severity of the ship's overall motion level, roll motion and vertical acceleration of the bow. The analysis is based on direct measurements of the vertical acceleration, pitch and roll motions, all of which may be recorded in the ship's superstructure. For most ships it was found (Lindemann, 1979) that stress monitoring was of less practical value and hence not recommended for a sensor. (This might not be true on larger, motions insensitive ships.) The principles underlying this module were well tested under the SO2 Project and are expected to be most useful in enhancing safe and efficient shiphandling in heavy weather.
* Guidance Information - The instrument automatically provides, in graphical form, information on how the ship's load picture will change with speed and heading. Guidance is provided for the vertical acceleration (Figure 14), probability of slamming, probability of shipping green water and the vertical bending moment. The guidance is given based on seakeeping analysis utilizing the ship as a wave buoy whereby an equivalent ideal Pierson-Moskowitz type sea state is determined. The guidance information is intended to show the influence of speed and heading. It is not recommended for speed and course optimization procedures since the technology, e.g. computation of the added resistance, forecasts of wave spectra and ship determined wave spectra, does not provide results of sufficient accuracy. The guidance information may provide debatable

results in mixed wave systems (where swell and wind-driven seas are both present), but in heavy weather dominated by wind-driven seas, the instrument should yield fairly reliable guidance. This solution is believed to be sufficient since most heavy weather situations consist of wind-driven seas.

* Response Estimator - This module derives through seakeeping analysis the probability of shipping green water, the probability of slamming and the vertical bending moment. The results obtained for slamming and green sea are displayed on analog meters. This module is the most uncertain in the instrumention system. Its success is completely dependent on the reliability of the seakeeping analysis and the applicability of the equivalent Pierson-Moskowitz wave spectrum method. However, it is hoped that the module can be calibrated in sea trials and thus prove to give additional useful information.

* Trend Analyzer - This displays in a graphical form the load history which could be used to evaluate the strategy of future maneuvers. Trends are given for the vertical acceleration of the bow, roll motion, green seas and slamming. A linear prediction technique on the trend was attempted, but was only found to yield reliable forecasts for the following 5-10 minutes. This is inadequate. Recent evaluations have however led us to believe that by the use of Auto-Regressive (Anderson, 1958) analysis, reliable forecasts can be given for the next hour. Forecasts are however not included in the present SO3 instrument. The Trend Analyser has been tried out in full scale and seems to be a useful addition to the information given by the condition monitor.

* Amplitude Detector - is activated when the motion level exceeds a preset level. The individually experienced motion amplitudes are detected and sorted out in a histogram. The histogram is saved together with recorded ship speed and course, date and time and the average motion level. The print-out may provide valuable information when reported damages are analyzed.

* Roll Warning Module - It monitors the ship's average roll motion period. Sudden changes in the period indicate possible stability problems and a warning is issued by the instrument. The module will not solve the complicated problem of dynamic stability and is not believed to play an active part in commonly encountered heavy weather conditions, but may, in following seas detect the possibility of an oncoming broaching situation. The wave system, wave-height, -period and -direction is detected automatically by the SO3 instrument. The method utilizes the heave and pitch motions and its response amplitudes. Through a linear regression analysis on these data and sea states, the wave system and heading angle are estimated.

The SO3 instrument was designed to fulfill the requirements of simple and reliable installation minimizing man/machine communication and to present results that are self-explanatory and do not require thorough education of the masters. These criteria have excluded certain more reliable technical solutions such as the detection of slams and green seas by direct measurements. However, the instrument is believed to be an important tool for ship mates when trying to ensure the safety of their ship, its cargo and the crew in heavy weather situations. The instrument is not only a safety device but can also give important information on when to change speed and/or course and thus improve the overall efficiency of the ship. In addition, the significant response level for roll, pitch, vertical acceleration and vertical bending moment together with derived wave height and period, are printed every fourth hour, or on command.

Maritime Administration (NMRC) Programs

The programs under which the SS LASH ITALIA, the USNS FURMAN and the M/V BURNS HARBOR instruments were developed stem from work started by the U. S. Ship Structure Committee over 20 years ago. It was then known that data were needed on hull stresses at sea, but it was not clear what could be done with such information. These initial efforts systematically collected hull stress data which were analyzed using statistical procedures. Parallel investigations were undertaken for the assessment of cargo loadings and securing requirements. Many other programs have been pursued, as noted above, toward using basic instrumentation technology for the purposes of ship response monitoring and data acquisition. As the theory of seakeeping became more fully developed and tools for its application confirmed, it became clear that routine utilization of this technology in ship operations was a possibility.

LASH ITALIA

Prudential Lines was seriously concerned about the problems of cargo and hull structural damage due to heavy weather operations of their ships. Under NMRC and Prudential Lines support, the LASH ITALIA was selected for installation of a modified Edo Corporation Heavy Weather Damage Avoidance System (Figure 15) for test and evaluation. This application included vertical and transverse accelerometers forward, and strain gages located at midships, on the foredeck, on the bow side framing and on the main deck aft of the deck house. The intent of the test and evaluation was to determine the appropriate manner and extent to which the modified HWDAS would be able to provide the ship's master with a reliable assessment of important seakeeping and operational safety occurrences. It is well to point out that early discussions at NMRC established the approach to the utilization of this technology as being of an informative nature. The interest in the application was to provide the master the best, most reliable and consistent information about ship responses. The use of this information, the making of specific decisions and the responsibility for same would remain in the hands of the master. It was believed that the master, possessing correct, reliable and timely information on the events experienced and to be expected, would be better able to make proper judgements. This would improve operational effectiveness and productivity and minimize adverse consequences.

The first phase of the test and evaluation on the LASH ITALIA got underway in the Fall of 1975. Operating in scheduled service between ports on

the East Coast and the Eastern Mediterranean, the ITALIA had ample opportunity to experience severe sea states in the normal course of service. Data from ten Atlantic crossings were subjected to analysis and reported by Hoffman (1976). It was clear that some of the anticipated events, such as carrying seas aboard aft of the deck house, were not a serious concern. Changes to the instrument including expanded capability were made during the next phase.

During the second phase (1977-1978) a parallel effort was included that used the data collection ability of the instrument for evaluation the U.S. Navy's Spectral Ocean Wave Model (SOWM), operated by the Fleet Numerical Weather Central. As a result of the experience with the LASH ITALIA and a better definition of the master's needs, the instrument is to be further expanded in sensor as well as computing capacity in a Phase III effort to begin in 1980.

LASH vessels launch and retrieve lighters using a gantry crane which spans the two cantilevers at the stern. An accelerometer will be placed at the stern to sense slamming of the afterbody. Structural failures have been noted by the shipowner on the flat, afterbody surfaces. A relative motion sensor will also be installed on the transom to assist in making decisions regarding cargo operations. It will establish the sea conditions and vessel motions which will allow more productive cargo operations while in exposed port conditions. To further assist the ship's officers in assessing at sea or in port rolling, a gyro will be installed at midships. This should lead to reduced cargo damage within the containers and lighters and improved cargo handling productivity. The system will also be provided with a static loader and CRT displays in the ship's cargo office and on the bridge. There will be more opportunity for officers to become familiar with the instrument and its utility.

FIGURE 15. PHOTOGRAPH OF INSTALLATION ON LASH ITALIA

FURMAN

In an effort to address problem areas similar to those with the ITALIA, but in a North Pacific environment, it was agreed to pursue a joint effort with a Military Sealift Command ship, the USNS FURMAN. The project sponsored by NMRC, Coast Guard, Navy and ABS has multiple purposes and interests as follows:

- To provide for test and evaluation of a Ship Monitoring and Guidance System (SMGS) having shipboard response analysis and information display for utilization in cargo vessel operations while under Optimum Track Ship Routing (Navy).
- To carry out assessment of human understanding and response to important ship response data associated with heavy weather ship performance.
- To evaluate the reliability and suitability of employing ship responses computed ashore using ship motion theory and the SOWM for decision making considerations affecting vessel routing.
- To evaluate basic considerations of tactical routing.
- To assess instrument performance and hardware reliability in a North Pacific environment.
- To determine training requirements for effective instrument utilization
- To establish installation and maintenance specifications

The FURMAN instrument is configured in much the same manner as the ITALIA. There are strain gages for midship bending and bow emergence/submergence, accelerometers for vertical and lateral sensing at the bow and a gyro roll indicator located in the engine room. The vessel operates out of the Pacific Northwest and has been under routing advisory for several years so that the historical performance is available. This provides additional background strength to the investigation. Test and evaluation plans call for several manned voyages each winter sailing season during which particular exercises and officer training will be undertaken. Although the instrument console is located at the 'tween deck level on the starboard side, there is a CRT display and keyboard on the bridge for information presentation and interaction.

BURNS HARBOR

The April, 1976 Great Lakes Seaway Port Development Shipper Conference designated the Maritime Administration as lead agency for the development of a stress warning instrument for Great Lakes vessels. Structural failures of large Great Lakes vessels as a result of heavy weather are rare. However, three of these

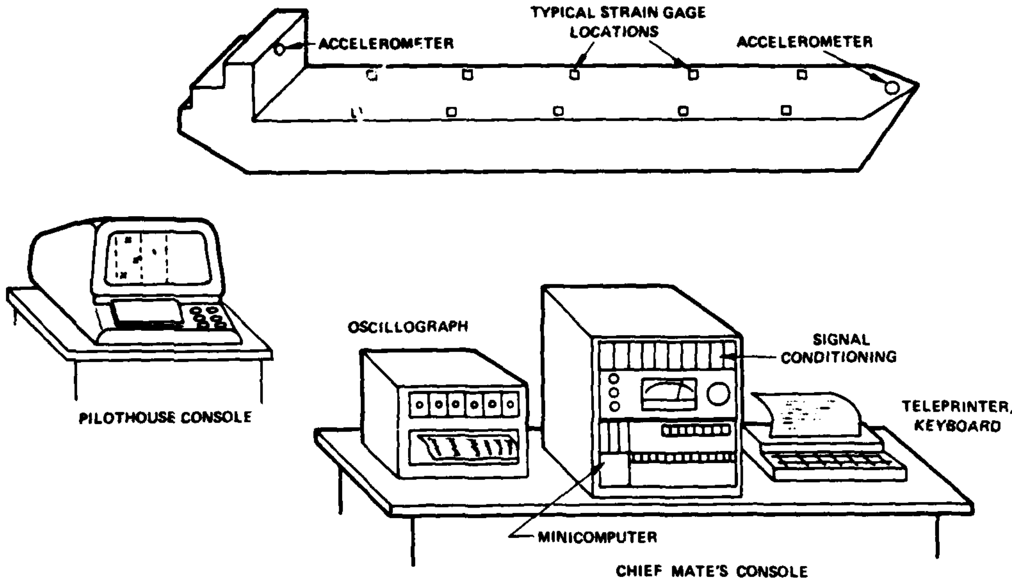


FIGURE 16. GREAT LAKES INSTRUMENT LAYOUT.

resulted in the total loss of the vessel with its crew: the CARL D. BRADLEY in November, 1958, the DANIEL J. MORRELL in November, 1966 and the EDMUND FITZGERALD in November, 1975. The MORRELL and the BRADLEY were lost due to structural failure in a storm. The cause of the FITZGERALD loss has not been attributed to hull girder structural failure, but boarding seas may have been a significant factor.

The need for a stress monitoring instrument is enhanced by the fact that the lengths of Great Lakes vessels have increased approximately 30% over the past 10 years with the opening of the Poe Lock at Sault Ste. Marie. This lock permits the transit of vessels of 1000 feet in length. These long ships are more flexible and thus more susceptible to high frequency dynamic stress variations. The importance of springing and the need for better control of hull loads and stresses during both the in-port operations and the at sea conditions have led to general recognition of the need for hull response monitoring instruments. An initial study (Lewis,1978) investigated the nature of the problem, the technology applicable and the recommended approach to the solution. The industry concensus was that the digital computer based instrument should be given further development, test and evaluation. The installation on the Bethlehem ore carrier M/V BURNS HARBOR will be the first application. The installation is depicted in Figure 16.

The sensors employed on this installation include sets of strain gages at five locations along the hull girder for sensing hull response due to static and low and high frequency dynamic loading. There is a vertical accelerometer at the bow and a lateral accelerometer on the bridge. Information is displayed on a CRT at several locations: in the wheelhouse, in the cargo control room and at the console. There will be major interest in determining the most meaningful information display, Figure 17.

HOLLANDIA

Dutch and British interests (Netherland's Maritime Institute, Delft University and Lloyd's Register of Shipping) joined together in 1977 and established a research program whose main objective was to investigate the use of on-board predictions on the influence of changes in speed and course to avoid critical responses and relate this to the choice of optimum speed based on a speed/power/fuel analysis. The different modules are:

* The Condition Monitor displays the severity of the load situation for the ship motions and longitudinal stresses. Full scale trials on the HOLLANDIA indicate that the module operates satisfactorily.
* The Trend Analysis module displays in graphical form the development of the ship's load history and might be used to evaluate the oncoming events. To our knowledge, the instrument was planned to project this trend over the next 3/4 hour. The success of this module has so far not been conveyed to people outside the project team.

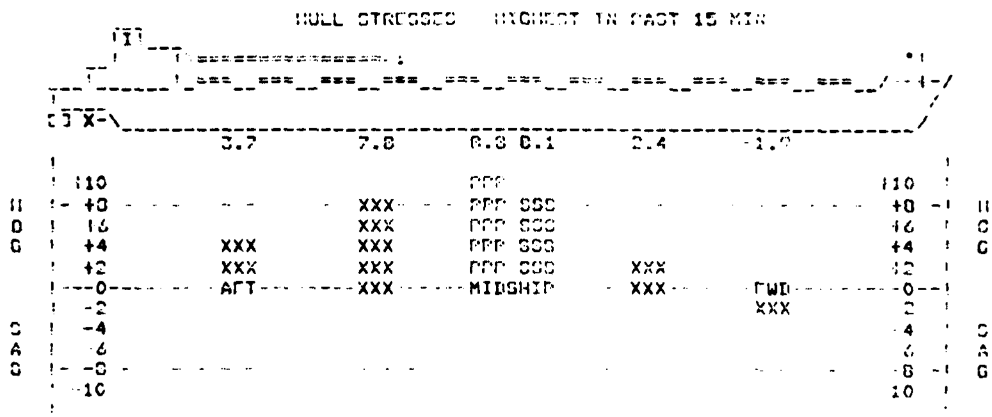


FIGURE 17. CRT DISPLAY OF GREAT LAKES INSTRUMENT

• The Guidance Information (wave loads) analyzes the wave load situation and advises the master on the minimum deviation from the present status that will be consistent with avoidance of critical responses. The procedure will require that critical responses are well defined and that the energy content of the wave systems is estimated quite accurately.

• The Guidance Information analysis (power loss) provides information on speed loss and fuel consumption for the advised course and speed obtained from the wave load guidance. Such guidance will, in order to yield valuable infomation, require a data-base with results that are quite reliable combined with a good estimate on the wave power spectrum. Reports obtained so far on this module are not given and its success must be questionable due to the relatively large uncertainties in the derived wave system combined with the uncertainties associated with added resistance data.

HELM

The HELM (Heavy Lifting Monitoring and Prediction) instrument is a digital computer based development of Hoffman Maritime Consultants. The instrument (Hoffman.1978) was designed as a commercial venture based on Hoffman's activites in the NMRC programs (ITALIA, FURMAN, BURNS HARBOR) reported in previous paragraphs. The instrument aids the superintendent in identifying and making use of available weather windows during heavy lift operations. Since the predictions are made under zero speed conditions and utilize wave buoy measurements as input, remarkable accuracy has been reported. The instrument also functions as a static loader and issues instructions for ballast compensation during extremely heavy lifts. Of all the instruments reported in the paper, the HELM has enjoyed the most operational experience, being installed on half a dozen craneships in the North Sea. Operation in a confined geographic area permits frequent visits by skilled technicians for servicing, and by engineers for training and crew orientation and system modification. (See Hoffman paper in this symposium.)

CONCLUSIONS

There are certain features common to all these instruments. The transducers, whether they are strain gages, accelerometers, pressure gages, or other, are designed to provide a calibrated signal for the phenomena to be measured. This signal has to be conditioned or processed and displayed in a meaningful way. During their initial development all instruments, except the SO3, relied heavily on the bending moment measured at midships and the accelerations measured at the bow. Bending moment is not a unique indicator of the structural integrity reserve in a vessel. The essential point to consider is that the technology exists to measure just about any response. How to interpret that measurement is the primary concern of research programs.

It is possible to reach specific conclusions:

• The concept of using response monitoring and prediction to aid the decision-making process of prudent seamanship has been established and its value proposed.

• The concept of using response sensing instruments to set operating limits has been suggested. It should be avoided into the foreseeable future. A great deal is still unknown about ship structural performance. As Admiral Price said at the 1975 Ship Structure Symposium, "When we fail, we don't know how close we were to success. When we succeed, we don't know how close we were to failure." Although we cannot be tempted to define operational limits using this technology, operational experience can be used to quantify and possibly to bound the concept of "prudent seamanship."

• The experimental development of this technology should be encouraged including the accumulation of substantially greater ship-years of experience on all ship types. Commercial application should proceed prudently. Recent improvements in the costs and capabilities of electronic components assure that the acquisition of this equipment will not be a burdensome expense.

• The importance of seakeeping training programs for ship's officers has generally been left to the end of the instrument development program. The S03 program is the one exception, and we conclude that training programs will require a significant effort.

• An assessment must be made of the reliability such instruments should have for commercial application. Poor strain gage reliability appears to have caused reevaluation of their use in favor of motion and other sensors for all the development programs.

• A study must be conducted to define operational requirements corresponding to ship type and characteristics.

• The "experimental" status of these "research" projects should be well understood. For the present, the information produced by these instruments should be treated with healthy skepticism. It is possible, in fact likely, that better information will lead to a more economic operation. However, managers must be cautioned that response monitoring equipment should not be used to mandate an upper limit to vessel operations. This technology is not thoroughly established and it would be unwise for a manager to subject any master to such dictates. Conversly, regulators and those charged with promoting safety should not believe that introduction of this technology will eliminate casualties. It is reasonable to believe that if properly used as an ADVISORY system, damages could be avoided or at least lessened. Unthinking, blind application and misinterpretation might produce the opposite result.

• Successful commercial use may be limited in the near term to applications where accurate decision-making is related to events of major economic consequence within confined geographic locations. The HELM concept appears to support this conclusion.

In summary, this technology should be encouraged and expanded. Every segment of the industry will benefit from it. The concepts discussed in this paper are fundamental to understanding the complexities of the marine environment and man's attempt to use it.

EPILOGUE

The purpose of the Epilogue as described in the Prologue was to permit the authors to disagree among themselves after their collaboration on the paper. There are no disagreements on the subjects discussed in the paper. The effort has served to provide an understanding of what was originally believed to be conflicting views. It is interesting that the change this past year did not result from any shifts in opinion on the part of any author, but rather from a better understanding of each persons' beliefs. The differences of opinion were due to communication rather than to philosophy.

We are united in our belief that if all marine structural research was undertaken in this manner, substantial improvements in efficiency and productivity could be achieved. We wish to encourage each of the programs; competition of ideas is meritorious. The field is so fertile that the programs conducted by one organization have not duplicated those of the others. We all need to understand the sea, the ship, and the sailor. We are challenged to identify the areas where knowledge can be quantified and those where it can not. The sea, the ship, and the sailor constitute a system, operated with purpose. Improving man's understanding of that system is most exciting!

REFERENCES

Anderson, T. W., The Statistical Analysis Of Time Series, John Wiley and Sons, New York, 1958.

Aertssen, G., "Laboring of Ships in Rough Seas", SNAME, Diamond Jubilee International Meeting, June 1968.

Boylston, J. W. and Boentgen, R. R., "Instrumentation - The Only Way", Ship Structures Symposium, SNAME, October 1975.

Chazal, E. A., et al, "Third Decade of Research Under Ship Structure Committee", Ship Structures Symposium, SNAME, October 1975.

Chazal, E. A., et al, "The Structural Requirements including Fracture Control for the hulls of the Proposed Nuclear Power Plants"; Third International Symposium of the Japan Welding Society, Tokyo, 1978.

Chen, Y. N., "Dynamic Response Of Large Great Lakes Bulk Carriers to Wave-Exited Loads", Trans. SNAME, 1977.

Carleton, H. and Winton, H., "Heavy Weather Damage Instrumentation Systems" Maritime Administration, National Maritime Research Center, NMRC-120A, 1974

Cardone, V. J., "Ocean Wave Prediction: Two Decades of Progress and Future Prospects", Seakeeping Symposium, S-3, Society of Naval Architects and Marine Engineers, New York, 1973.

"Course for Shiphandling in Rough Weather", Report S03-10, June 1978. (in Norwegian)

Dalzell, J. F. et al, "Examination Of Service and Stress Data Of Three Ships for Development of Hull Girder Criteria", Ship Structural Committee. SSC-287, Washington, D. C., 1979 NTIS AD-A072910.

Dalzell, J. F. "Wavemeter Data Reduction Method and Initial Data for the SL-7 Containership", Ship Structure Committee, SSC-278, Washington, D. C., 1978, NTIS AD-A062391.

Faltinsen. O. and Michelsen, F. C., "Motions of Large Structures in Waves at Zero Froude Number", Int. Symposium on the Dyn. of Marine Vehicles and Structures in Waves, London, 1974.

"Final Report Of Working Panels", First Review Meeting, U. S. Great Lakes-Seaway Port Development and Shipper Conference, Cleveland, Ohio, October 3 and 4 1977.

Gerritsma, J. and Beukelamn, W., "Analysis of the Resistance Increase in Waves for a Fast Cargo Ship", Int. Shipbuilding Progress, 1972.

Gran, S., "Guide-Light System For Motion Sensitive Marine Operations", Det norske Veritas Report 79-0323, February 1979.

Gran, S., "Full Scale Measurement Of Springing Contribution to Extreme Stress and Fatigue in a Large Tanker", Det norske Veritas Report 76-417, December 1976.

Gran, S., "Springing Responses in Random Seas", DnV Report 73-22-S, November 1973.

Gregov, Z. and Finch, R., "Hull Monitoring System, Volume 1", Maritime Administration, MA-RD-920-78059, August 1978.

Haddara, M. R., et al., "Capsizing Experiments with a Model of a Fast Cargo Liner in San Francisco Bay", Final Report, U. S. Coast Guard Project 723411, Jan. 1972.

Harding, E. T. , and Kotsch, W. J., Heavy Weather Guide, Naval Institute Press, Annapolis, 1965.

Hoffman, D., "The Use of the Spectral Ocean Wave Model (SOWM) in Predicting Ship Responses", Maritime Administration, NMRC-KP-192, 1979.

Hoffman, D., "A Feasibility Study on the Evaluation of the Spectral Ocean Wave Model as a Tool for Ship Response Prediction", Maritime Administration, NMRC-KP-179, 1978.

Hoffman, D., "Heavy Weather Damage Avoidance System (HWDAS) on the LASH ITALIA", Maritime Administration, NMRC-KP-177, 1977.

Hoffman, D. and Fitzgerald, V. K., "Systems Approach to Offshore Crane Ship Operations", Trans. SNAME, 1978.

Hoffman, D., "Impact Of Seakeeping on Ship Operations", Marine Technology, July 1976.

Hoffman, D. and Walden, D. A.,"Environmental Wave Data for Determining Hull Structural Loadings", Ship Structure Committee, SSC-268, Washington, D.C., 1977 AD-A047116.

Hoffman, D., and Lewis, E. V, "Heavy Weather Damage Warning Systems", Maritime Administration, NMRC-KP-143, 1975.

Johnson, R. E. and Swann, B. R. "National Transportation Safety Board's Role in Marine Safety", Chesapeake Section Paper, SNAME, September 26, 1979.

Korvin-Krovkovky, Theory of Seakeeping, SNAME, New York, 1961.

Lewis, E. V., "The Status Of Naval Seakeeping Research", U.S. Naval Academy Report EW-16-79, October 1979.

Lewis, E. V., et al, "Great Lakes Carriers Hull Stress Monitoring System", Webb Institute Center for Marine Studies, January 1979, NTIS PB 295537/AS.

Little, R. S. and Lewis, E. V., "A Statistical Study of Wave Induced Bending Moments on Large Oceangoing Tankers and Bulk Carriers", Trans. SNAME, 1971.

Lindemann, K., Oldand, J. and Streengehagen, J., "On the Application of Hull Surveillance Systems for Increased Safety and Improved Structural Utilization in Rough Weather", Trans., SNAME 1977.

Lindemann, K., "Hull Surveillance of Improved Ship Handling in Rough Weather", DnV Report 74-54-S, October 1974.

Lindemann, K., "Improved Ship Handling in Rough Weather through Hull Surveillance", Norwegian Maritime Research, 1975.

Lindemann, K. and Nordenstrom, N., "A System for Ship Handling in Rough Weather", Proceedings 4th Ship Controll System Symposium, Royal Netherlands Naval College, 1975.

Lindemann. K., "The Navigator, Ship Handling in Rough Weather and Hull Surveillence Systems", First International Conference on Human Factors in the Design and Operation of Ships, Gothenburg, Sweden, Feb. 1977.

Lindemann, K., "Hull Surveillence" SDS Report Subproject no 40/41, November 1975.

Lindemann, K., "Human Factors in the Design and Operations Of Ships", Proceedings of the First International Conference on Human Factors, Sweden, February 1977.

Lindemann, K., "An Investigation of the Response Characteristics of Conventional Ships with Emphasis on Handling of Ships in Heavy Weather". DnV Report 77-584, December 1977.

Lindemann, K., "Notes on Response in Heavy Weather", DnV Report 77-584-SOM, February 1978. (in Norwegian)

Lindemann, K., Lunde, S., "Full Scale Measurements on the T/T ESSO BONN; a Brief Analysis of Results obtained by a Tour Recorder", SO3 Report, October 1978.

Lindemann, K., "An Evaluation of the Need to Measure Stresses in Practical Hull Surveillance Systems", Det norske Veritas Report 79-0603, September 1979.

Marine Accident Report: Capsizing and Sinking of the OCEAN EXPRESS near Port O'Conner, Texas, April 15, 1976, National Transportation Safety Board, April 5, 1979.

Marine Accident Report: SS EDMUND FITZGERALD Sinking in Lake Superior on November 10, 1975, National Transportation Safety Board, May 4, 1978.

Marine Accident Report: Sinking of the SS DANIEL J. MORRELL in Lake Huron on November 29, 1966, National Transportation Safety Board, March 4, 1968.

Marine Casualty Report: Structural Failure and Sinking of the TEXACO OKLAHOMA off Cape Hatteras on 27 March 1971, with Loss of 31 Lives, Marine Board of Investigation and National Transportation Safety Board Actions, 26 July 1972.

Marine Casualty Report: Foundering of the SS CARL D. BRADLEY, Lake Michigan, 18 November 1958, with Loss of 31 Lives, Marine Board of Investigation, 7 July 1959.

Mostert, N., Supership, Alfred Knopf, New York, 1974.

Ocean Wave Measurement and Analysis, Proceedings of the International Symposium, New Orleans, Volumes I and II, American Society of Civil Engineers, 1974.

Oakley, O. H., et al, "A Summary of Wave Data Needs and Availability", Ship Research Committee, Washington, D. C., 1979.

Papoulis, A., Probability, Random Variables and Stochastic Processes, McGraw-Hill, New York, 1965.

Pierson, etal, Practical Methods for Observing and Forecasting Ocean Waves, U. S. Navy Hydrographic Office, Publication No. 603.

"Principal of Operation for the SO3 Hull Surveillance System; A Macro Flow Diagram", SO3 Report, December 1978.

Principles Of Naval Architecture, The Society Of Naval Architects and Marine Engineers, New York, 1967.

Proceedings of the Seventh International Ship Structures Congress, Institute de Research de la Construction Navale, Paris, 1979.

Report of Committee I.1 of ISSC, 1979

Rolfe, S.T., et al, "Fracture-Control Guidelines for Welded Steel Ship Hulls", Ship Structure Committee, SSC-244, Washington, D. C., 1974 NTIS AD-A004553.

Rolfe, S. T. and Barsom, J. M., Fracture And Fatigue Control in Structure, Prentice Hall, Englewood Cliffs, New Jersey, 1977.

St. Denis, M. and Pierson, W. S., "On the Motion of Ships in Confused Seas", Trans., SNAME, 1953.

Salvesen, N., Tuck, E. O. and Faltinsen, O., "Ship Motions and Sea Loads", Trans. SNAME, 1970.

Salvesen, N., "Added Resistance of Ship in Waves", Journal of Hydronautics, Jan. 1978.

Schmitke, R. T., "Ship Sway, Roll and Yaw Motion in Oblique Seas", Trans., SNAME, 1978.

Skjordal, S. and Faltinsen, O., "A Linear Theory of Springing", Journal of Ship Research, in publication.

Skjordal, Svein, A Rational Ship Theory Approach for the Evaluation of Springing, Norwegian Institute of Technology, Trondheim, January 1978.

Strom-Tejsen, et al, "Added Resistance in Waves" Trans. SNAME, 1973.

Troesch, A., et al, "Ship Springing: Experimental and Theoretical Study", Department Of Naval Architecture, University of Michigan, 1980.

Taylor, K. V. "Onboard Guidance for Heavy Weather Operation", Institute of Marine Engineers, Operation Of Ships in Rough Weather, London, England, February, 1980.

vanGunsteren, F. F., Springing Of Ships In Waves, Deft University Press, The Netherlands, 1978.

Witkin, "The Perception of the Upright", The Scientific American, February 1959.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
One World Trade Center, Suite 1369, New York, N.Y. 10048
Spring Meeting/STAR Symposium, Coronado, California
June 4-6, 1980

Status Report On the Application of Stress and Motion Monitoring in Merchant Vessels

No. 17

Edward A. Chazal, Jr., Member, U.S. Coast Guard, Baltimore, Maryland
H. Paul Cojeen, Associate Member, U.S. Coast Guard, Washington, D.C
Kaare Lindemann, Visitor, Det Norske Veritas, Oslo, Norway
Walter M. Maclean, Member, National Maritime Research Center, Kings Point, New York

Discussion and Authors' Closures

NORMAN O. HAMMER (M)
Maritime Administration

The authors have succeeded in preparing a thought-provoking "think" paper. In fact, the initial reaction of this discusser after reading the paper was to ask the question, "What are these gentlemen trying to say?" However, reflecting on this question over a number of days, it is believed the key message is fourfold, namely: (1) there is a need to increase the communication between the master (and mates) and the behavior of the vessel to the environment (i.e., seakeeping in waves) to ensure safe operation; (2) the overall topic is quite complex, and there are many factors to be considered; (3) here is a status report on seven instrumentation research programs; and lastly, (4) what do you readers think about the subject matter.

This discusser shares the authors' view that there is need to increase the "feel" of the master and mates to the ship behavior. One may recall that back in the days of sail, it was important that watch stations be located out in the open and exposed to the weather. Even when the marine industry advanced to steam-propelled ships, it took decades before there was acceptance of the enclosed wheelhouse concept. If the objective today is to give masters a better "feel or indicator" of vessel behavior, beyond the highly reliable but subjective human senses they currently possess, one should not aim for a highly complex system with a large number of indicators displaying necessarily the maximum stresses or motions experienced on a vessel since such a system will, undoubtedly, be prone to malfunctions or "Murphy's Law." Rather, emphasis must be placed on achieving total confidence in the long-term reliability of only a few indicators.

Therefore, it would appear that the next stepping stone beyond the projects described in the paper should be to aim for a simple system consisting of no more than 2 or 3 sensing devices that can be installed on perhaps twenty (20) different ships. Since personnel move between companies and ships, there should be a common element between the "indicators" placed on containerships as well as tankers. Also, if the concept is to succeed, many shipyears of experience will be needed before shipboard personnel acceptance has been achieved.

The last aspect that needs to be discussed is that of timing. This really calls for an assessment of the state-of-the-art of instrumentation performance demonstrated by previous and current research programs. Here, review of Table 1 at first glance is not very encouraging. However, if one can accept the view that only 2 or 3 indicators should be selected, it may be possible to move forward now from "experimental" to "operational" systems. If on the other hand technology for such a system is not presently available, it will probably take another decade before there is any improvement in the information available to ship masters to supplement the subjective human senses they currently use for safe navigation of their vessels. A wait of one or more decades is too long; therefore, the time has come to focus the effort on only 2 or 3 indicators.

Again, congratulations to the authors on an excellent, thought-provoking paper.

G. H. PATRICK BURSLEY (V)
National Transportation Safety Board*

A safety recommendation made by the National Transportation Safety Board in 1972 (M-72-20) appears to have been the first formal call in the United States for the mandatory installation of hull stress monitors and a predictive capability in respect to probable stresses on a vessel with a view to facilitating evasive ship maneuvers. In retrospect, that call appears to have been premature in respect to practical application of then-developing technology; but the call did initiate an ongoing dialogue between the Coast Guard and the National Transportation Safety Board which appears to

have intensified the Coast Guard's consideration of the merits of such systems. Certainly, the dialogue reflects the development of a more positive attitude on the part of the Coast Guard toward such systems as technology has developed. It seems clear, also, that the pace of research has intensified and that MarAd, ABS and industry have taken up active roles in addressing the matter. The instant status report is, therefore, a timely and positive contribution to future development of the systems.

As a discusser whose experience is more closely related to that of masters and deck officers than to that of naval architects, I found my attention focused on the elements of the problem related to the sailor and, in particular, to the very real fact that technology can readily provide him with more information than he can effectively utilize. Also noteworthy, in my estimation, are the current limits of our knowledge regarding the levels of stress the hull girder can tolerate in a seaway. Until our knowledge of this factor is significantly improved, reliance on the sailor's experience and senses should continue to be determinative of the evasive action which is to be taken. It would seem, also, that until it is possible to confidently predict that stresses are reaching intensities where caution is indicated, the shipboard systems will have to be regarded primarily as sources of data for naval architects rather than as effective operational aids for the sailor.

A critical factor in future research should be the human engineering of the display so as to promote proper reactions by mariners. There is an emerging recognition in the field of accident investigation that so-called human error--increasingly identified as the probable cause of many accidents as the reliability of transportation vehicles has improved--needs to be explored in still greater depth to determine if underlying design factors are inviting human error. The display of stress and motion data must be unambiguous, and provide information of ready practical use to the mariner if it is to avoid leading him into mistakes. Further, as against the possibility of a breakdown in the monitoring system, the data selected for display must not divorce the sailor from a concurrent appraisal of the physical sensory indications he has relied on historically.

In my view, the installation of stress and motion monitoring systems will have a significant impact on training regimes for mariners far beyond the training associated with the use of the monitoring systems and the interpretation of the data derived from them. There will be an associated need for far more sophisticated training in the full gamut of seamen's skills. Thereby, we may face a new quandary; the need to man vessels with mariners with the upgraded technical credentials necessary to effectively utilize the monitoring systems could further reduce the numbers of mariners with sufficient experience to develop "seaman's senses." If this happens, we will need even more sophisticated monitoring systems. Yet, it was the attenuation of the physical sensory indicators used by seamen that accompanied the development of more sophisticated vessels which triggered the need for the supplementary sensory systems discussed in this paper.

*The views expressed herein are the personal views of the discusser and do not necessarily represent the views of the National Transportation Safety Board.

CHARLES B. WALBURN (AM)
Bethlehem Steel Corp.

I would like to thank the authors for successfully bringing together a large amount of material representing diverse approaches and viewpoints, and distilling it into the concise yet comprehensive and, indeed, comprehensible paper which they have presented.

As owners and operators of vessels on the oceans and Great Lakes, Bethlehem Steel has had a long-standing and active interest in safety at sea, both from the standpoint of vessel design and vessel operations. Therefore, I consider that we fall into the category of potential users, as described in the abstract, and that the paper is directed to us. Moreover, we qualify as indirect participants in the paper to the extent that we have cooperated in various longitudinal hull strength research programs since 1971. We currently have two Great Lakes vessels fitted with analog hull stress monitoring systems; and, as has been stated by the authors, we are cooperating in a MarAd project with Hoffman Maritime Consultants and Teledyne Engineering Services for the development of digital hull stress monitoring and guidance system, also for Great Lakes application.

Addressing the contents of the paper specifically, I would offer comments as follows:

The subject of crew experience is taken up on page 270. The authors' points are well taken insofar as the changing hull arrangements, crew rotation schedules and modern weather forecasting techniques having effects on experience. Without going into detail as to the specific effects these changes have had in crew experience, I must, however, take issue with the statement that the level of experience is

declining. Even in the context presented, this terminology can wrongly be taken to imply a trend toward decreased professional expertise, laxity in operational discipline, hiring procedures or training standards, or that crews may be sent to sea improperly prepared to accept the risks and responsibilities involved. We have taken all possible steps to prevent this from occurring and are confident that this is not what the authors intended. Suffice it to say that whatever its present nature or level, the base of experience of today's crews on modern vessels will be enhanced tremendously by the potential refinements to personal perception afforded by advanced systems for navigation, weather forecasting and hull monitoring. I fully expect that the net effect will be to tip the scale on the side of safety in respect of the balance between traditional operating experience and vessel size.

With respect to the application of computerized hull monitoring systems to decision-making or for vessel schedule and operations control, as is discussed on page 276, I strongly support the viewpoint of the authors that these uses should not be exercised even if technologically feasible. The hull stress monitoring and guidance system has been conceived only as a tool, an informational aid to the master. We believe that a hull monitoring system should no more require a master to act than a fuel gauge requires a motorist to buy fuel. In each case, a choice exists whether or how to use the information provided by the respective instrument, and the objective is to make available that information which can best contribute to more educated and confident operational decision-making. It is neither the intent nor desire of shoreside staff to direct the master regarding his speed, heading, ballast or decision to proceed to sea, nor to derogate in any way his responsibility as concerns the safety of his vessel. The only guidelines for vessel operations that originate ashore suggest maximum levels of vessel response acceptable for normal operations, at the onset of which steps to ease laboring may be advisable depending on existing conditions as evaluated by the master. This is in direct opposition to the possibility feared by the authors that company management might require certain minimum levels of vessel response to be exceeded in order to justify speed or course changes. Our conservative attitude toward safety has governed in the past and will continue regardless of increased sophistication of the feedback loop.

The issue of alerts and warnings has proven to be a source of active debate, and the authors have ably demonstrated many of the opposing viewpoints. I presently support the view that the best solution is an adjustable alert capability which can be used at the discretion of the master, assuming he is prepared with sufficient training in the areas of hull stress and the use of the stress monitoring system, and with a proper understanding of the various design and regulatory allowable limits applicable to his vessel. This area is subject to study and will be considered during the evaluation phase of the MarAd Great Lakes development program. We will also be very interested in comparing these results with those forthcoming from the other programs enumerated by the authors as well.

The data presented in Tables 1 and 2 is of particular interest as it provides capsule summaries of vessel monitoring research under many different programs and from many sources, which tends to broaden the scope and understanding of we "users" and those involved in other ongoing research programs. Of particular interest is the emphasis placed on crew training in the SO3 project. Although, as noted above, this area is not the primary thrust of the MarAd Great Lakes project, it is of crucial importance to assure proper interpretation and use of the new information the hull monitoring system can provide.

It is worthy of note that despite the disparity of approach of the research programs reported on and also the diverse backgrounds of the authors, the paper's conclusions are so positive and cohesive. Moreover, it is surprising yet very reassuring that after initially agreeing to disagree, the authors' anticipated differences did not materialize but their viewpoints were found to be mutually supporting. This bodes well for the future in terms of vessel safety and serves as a milepost of progress toward providing masters with data which is vital to intelligent decisions.

I would like to add my congratulations to the authors for their excellent presentation of this status report, and close with the hope that the results of the ongoing research and the additional research called for by the authors, when concluded, will be given an equally high level of exposure in this forum.

JOHN W. BOYLSTON (M)
El Paso Marine Co.

The paper, "Status Report on the Application of Stress and Motion Monitoring in Merchant Vessels," represents an excellent overview of ship instrumentation and damage avoidance gear as it stands today and for the near future. In my years in the marine field, I have developed a pattern which I think is borne out again in this general field. It starts with the designer who has to go beyond that which exists and who thus enlists the aid of

the theoretician to extrapolate that which has gone before. The theoretician does his best, but usually tells you he doesn't have enough data. When the first structural problem occurs, the theoretician's initial reaction is that the failure is *not* possible; however, with repeated failures he becomes interested and indicates all can be fixed if he has some more data. After you instrumentate and gather the data, the theoretician models the structure, assumes a loading based on previous studies and concludes again that since the model doesn't match the structural damage, that naturally the structural damage never occurred in the first place. On second thought, however, he concludes with additional load data, a better model can be made. After obtaining three-light years of wave and load data sufficient for statistical analysis, either the model matches wherein the theoretician concludes that yes, you did have that structural damage, or with a bad model fit he concludes you have obliviously run into wave spectra outside of his assumed spectra. He then cautions you not to run your ship in those type of waves any more. By this time you have put a doubler on the area which has held up fairly well. The theoretician adds the doubler to his structural model and concludes that the stress level has been reduced satisfactorily, based on his limited data.

On the serious side, I believe I am qualified to discuss stress monitoring having been associated with two SSC vessel instrumentation programs and an evaluation program of a U.S.-manufactured damage avoidance system. Based on my experience in the SSC programs, I think strain gauges and their associated wiring are the most reliable shipboard components available. Based on the damage avoidance unit trial and my present experience, I think computers are the most unreliable piece of equipment that can be placed in the marine environment. Voltage surges or power failures wipe out computer memories, usually in heavy weather when they are needed. Manned instrumentation programs are necessary to take care of the signal conditioners, recorders and other hardware, not the strain gauges. A simple reference gauge will tell you if your other gauges are calibrated correctly.

I think the realities of the marine industry are important and have been missed. The vessel operator who places schedule above all else will damage his ships as he encourages his masters to take risks. He won't buy a damage avoidance system. The master who thinks management wants schedule maintenance above all else will not use the system (it will be down for some reason) as recorded data could cost him his license.

The prudent operator and prudent master would welcome a damage avoidance tool, but we should all be aware that unlike most professions, the master has the absolute total authority and responsibility for his actions. The competent master must, of necessity, be provided with a simple, reliable tool in which he has confidence or he will not use it.

My greatest concern in this regard would be for the less competent master who is more likely to use a total damage avoidance system (go or no-go type) as a "crutch." His own inability to make a decision based on basic data is supplanted by a computer decision output upon which he totally relies.

In my opinion, the industry would be better served by the following program:

1. After interviews with worldwide operators and classification societies, categorize damage by ship type. I believe this has already been done to a large extent.

2. Support instrumentation programs where single vessels of various "standard" types are fully instrumentated with a manned *instrumentation program*.

3. As a result of "1" and "2" above, isolate those areas of concern on each ship type.

4. Provide a simple strain gauge and/or accelerometer direct readout system as an industry package for each type of vessel with options that can be added.

5. Allow the operator with his classification society (and possibly his underwriters) to prescribe limits of operation which would be provided in a user guide for the master.

The U.S. Coast Guard authors of this paper should be well aware of the legal ramifications of collision avoidance radar. It would seem that the same constraints would apply to a damage avoidance system. I, therefore, suggest that the regulatory bodies and vendors involved keep in mind the total scope of the marine industry in addition to hardware advances as they go forward.

PETER A. FISHER (M)
Matson Navigation Co.

The authors are to be thanked for their interesting paper summarizing the developments in the area of monitoring vessel motions and stresses. In the various factions associated with the marine industry, the ability to measure environmental excitation and resultant vessel response means *many* things. To the research scientist it provides a chance to

compare theoretical and experimental predictions to full-scale experience. To the engineer, the regulatory agency, the operator and the owner it supplies much-needed input for the establishment of safe design and operating limits. If each of the above groups was asked to develop a specification for such a monitoring system, breaking out costs and system requirements, the range between answers would be phenomenal.

Speaking from the "moderate, rational" viewpoint of the operator/owner, any system would have to be inexpensive, reliable, i.e., maintenance free, and unrestrictive to vessel operations. We are concerned with the safety of the vessel, its personnel and cargo. Anything which would support these ends would be heartily welcomed aboard ship. If, however, it could not be cost justified (and how do you quantify and qualify safety) or if it simply generated meaningless paper, its value would be greatly diminished.

On a carefully designed containership, as many as half of the containers are carried on deck exposed to the environment. They are restrained from movement by a system of pins and/or lashings. On the one hand, there is a concern to avoid vessel motions which could cause failures in the container lashing system. On the other hand, is the design of the container restraint system itself. A method of accurately determining motions and associated forces would assist in dealing with both of these problems.

Recently, two very different container vessels were outfitted with instrumentation designed to assess ship motions and the forces that on-deck containers might expect to experience. Other than professional interest, the object of the project was to evaluate the cargo lashing system with regard to adequacy. Additionally, there was interest in replacement of lashings by an improved container restraint system. The results of the study were valuable, albeit limited, in that they pointed out significant differences between vessels, and more important, between theoretical prediction and experience. This is merely one example of the value of a system of monitoring motions and forces with benefit for both design and operations.

Professionally, as an industry we have been in operation for years, relying on empirical data pretty much exclusively. However, moving forward intelligently must be accomplished through increased knowledge. As naval architects we must welcome this move realizing that the cost of development and implementation rests on the cooperative efforts of our industry.

JOHN F. DALZELL (AM)
Davidson Laboratory
Stevens Institute of Technology

The authors concentrate very properly upon the main objective of stress and motion monitoring systems, which is to aid in the safe and efficient operation of ships at sea. It is thus understandable that relatively little emphasis is given to a potentially important long-range by-product of the systems discussed. This, as this discusser sees it, is the data from which better quantitative design criteria may be derived for such things as slamming, shipping of water, etc. There is little doubt that the contemporary ship motions technology alluded to in the paper is able to differentiate between alternate design concepts. Whether or not the technology is capable of saying that a design is acceptable in the absolute sense depends upon the existence of firmly grounded quantitative criteria which take the reactions of the "prudent master" into account.

H. H. CHEN (M)
American Bureau of Shipping

The authors have attempted to review the state-of-the-art of the application of stress and motion monitoring systems related to safety and operation of ships. Due to the broad coverage presented in the paper regarding the application of a monitoring system, the authors' effort is ambitious, and their presentation of such kind of work should be encouraged.

As pointed out by the authors, a monitoring system can have multiple applications. It can provide information to the ship's master regarding changes of ship's speed and/or heading to reduce operational damages. It was also indicated in the paper that a monitoring system could be used as a means for data collection which would, in turn, be employed by the classification societies and regulatory agencies to assess existing scantling requirements. However, it should be noted that the present safety standard as reflected in the ABS Rules has been arrived at based on a valid mathematical theory applied in conjunction with a credible data base. Prior operational experience also played a significant role in the establishment of the Rules, but the Rules should not be viewed as solely based upon past operational experience. In this regard, I would like to offer some brief remarks regarding the data base used in the present strength standard of the ABS Rules.

A data collection program was, in fact, started in the early 60's when the Ship Structure Committee sponsored two full-scale instrumentation programs on the S.S. HOOSIER STATE and S.S. WOLVERINE

STATE. The programs were very significant in that the data collected formed the basis for establishing the so-called long-term prediction procedure of the American Bureau of Shipping (ABS) (See Reference [1] and [2]). Later in 1967, ABS instrumented five large ships, including four tankers and one bulk carrier (3). Following successful correlation with the collected data, this long-term prediction procedure has been employed in the development of the present ABS Rules requirements on ship hull girder strength.

In regard to the strength of Great Lakes ships, wave-induced bending moments at higher frequency (springing) makes the problem more complicated than that for oceangoing ships. A theoretical study initiated at ABS in 1974 formed the basis of the 1978 ABS Great Lakes Rules. Furthermore, in 1978 another research project on theoretical and experimental studies of springing was sponsored by ABS and MarAd to thoroughly investigate the combined wave-induced and springing bending moments, using model tests of a Great Lakes bulk carrier. Both studies have revealed that the springing bending moment can be generated by short waves and long waves. The significance of the nonlinear behavior due to long waves has not been acknowledged in the present paper.

The prediction of ship springing was characterized by the authors as one of the areas where the state of technology requires further research. I am pleased to mention here that a two-year research project will be jointly sponsored by ABS and MarAd for further investigation of the nonlinear wave-induced springing. It is hoped that springing can be better understood through this research project and that a more reliable mathematical tool for predicting springing responses can be established by this research effort.

References:

1. Band, E.G.U., "Analysis of Ship Data to Predict Long-Term Trends of Hull Bending Moments," American Bureau of Shipping, November, 1966.

2. Lewis, E.V., "Predicting Long-Term Distributions of Wave-Induced Bending Moment on Ship Hulls," Proceedings, Spring Meeting, SNAME, 1967.

3. Little, R.S. and Lewis, E.V., "A Statistical Study of Wave-Induced Bending Moments on Large Oceangoing Tankers and Bulk Carriers," SNAME, Transactions, 1971.

DAN HOFFMAN (M)
Hoffman Maritime Consultants

When four individuals respresenting a diversified school of thoughts and three different organizations, each pursuing its own goals, decide to join forces and to write a paper on a controversial subject, the probability of success should have normally been very low. However, much to my delight, this is not the case at all; and I would like to commend the authors for "agreeing to disagree" so elegantly. I cannot consider myself an unbiased discusser simply by virtue of being heavily involved in four out of the seven programs listed in Table 2. I hope, however, my comments will be of some value to the authors and their audiences.

My general comment can be best conveyed in relation to Tables 1 and 2. Though it represents a fair attempt by the authors to summarize the current state-of-the-art, it is somewhat misleading since it lacks the means of acquainting the reader with the historical development of these programs which is crucial for an objective assessment of the current status. One cannot evaluate the program under Item (1) along with those in (2) and (7) since the scope and goals were quite different. By attempting to fit it in the Table 1 matrix, the reader who is not familiar with the details may get a distorted picture. Ideally, the program under (1) should have been mentioned but not tabulated or, if so, in a separate table along with the original programs in Norway (Lindemann, 1974) and the USA (Hoffman, Lewis, 1975). Furthermore, the five programs which are lumped into one program are different in many respects and cannot be classified together. This is clearly demonstrated in the Hoffman-Lewis 1975 paper.

The LASH ITALIA, SO3, HELM, FURMAN, and BURNS HARBOR were all essentially the results of earlier programs which were initiated in Norway (1970) and in the USA (1972). The initial designs, not shown in Table 1, have undergone a lengthy process of initial concept formulation and, consequently, several changes and modifications. The above five programs represent the results today, and the dates shown in Table 2 are, therefore, misleading. The HOLLANDIA, by contrast, was somewhat of a late comer and to some extent benefited from the previous programs, yet in other respects, substantial findings of earlier programs were ignored and re-evaluated by the Lloyds-NMI Program. Table 1 should therefore be referred to with extreme caution as an initial input only with all the pertinent references close in hand.

My other comments are more limited and refer to specific statements by the authors.

One of the methods currently used to input the prevailing sea conditions is by means of manipulating measured responses with theoretically calculated values to yield an estimate of height and period of the wave and possibly directionality. Several of the systems (SO3, HOLLANDIA, BURNS HARBOR), already including such software and modifications on board the FURMAN, are likely soon. This aspect should be added to the section entitled "The Sea" under the chapter "Identification of Problem Areas and Needs."

The following section under the same chapter refers to the "Ship" and is devoted primarily to training plans which are no doubt a key to success of any such program or system. There exists some controversy as to the detail and method of training. The SO3 project advocates textbooks and courses which, in my opinion, may be suitable if given to cadets in Maritime Academies or to officers during regular upgrading courses. I do not believe that an attempt to subject the officer to an intensive one-week course will be a workable solution in most cases. Furthermore, my prior experience of educating seagoing officers indicated that most statistical aspects as well as mathematical formulations beyond an elementary level should be excluded. I, therefore, believe that some basic concept definition has still to be made in this area before specific recommendation for training can be made. Our experience on board merchant vessels of different types is that the availability of an observer who is familiar with the system, the vessel and the various theories involved during a voyage is an extremely effective way of training, however, not necessarily very cost-effective.

Under the section entitled DEVELOPMENT PROGRAMS, the BURNS HARBOR does not receive its proper due attention from the authors-- probably, because the system was not completed until late March of this year and is currently being installed on the vessel in anticipation of the first manned voyage to take place during the fall of this year. The Hull Stress Monitoring and Guidance System on the BURNS HARBOR represents one of the more advanced systems to date on board seagoing vessels, and I hope that the results obtained will justify a dedicated paper on the subject in the near future. It is also an example of collaboration between the owner (Bethlehem Steel), the sponsors (Maritime Administration and the United States Coast Guard), and the manufacturers (Hoffman Maritime Consultants, Inc., with Teledyne Engineering Services as subcontractors) which led to the design, installation and evaluation of the system.

Finally, I do not want to elaborate further on the HELM system since an entire paper was presented before the Society not too long ago, but I would like to add that the technology which was developed and tested on board crane vessels has since been extended to various other vessels, including Emergency Support Vessels (ESV) of the semi-submersible type and Multi-Support Vessels (MSV)--both mono hull as well as semi-submersible--and, most recently, a large semi-submersible for drilling north of the 62nd latitude in Norwegian waters. This may serve as an indication as to the versatility of the system and its applicability to a wide variety of environmentally sensitive operations at sea.

I would like to commend the authors again for their excellent status report which I am sure will turn into a major reference paper in the future.

References:

1. Clune, W.M., "Optimum Track Ship Routing at Fleet Numerical Weather Central, Monterey," Mariners Weather Log (19:1), January, 1975.

2. Hoffman, D., and Petrie, G., "Shipboard Guidance for Operation in Heavy Weather," AIAA Journal of Hydronautics (12:4), October, 1978.

EDWARD V. LEWIS (HM/FL)
Consulting Naval Architect

This paper provides an interesting and valuable summary of work being done on developing and installing shipboard instrumentation to monitor ship responses to rough seas and to provide guidance to deck officers.

Two objectives for such instrumentation are clearly brought out. One is safety--of the crew, passengers (if any), the marine environment and the ship itself (including local structure and deck outfit). The other is improved economics of ship operation, covering avoidance of damage to cargo and minimizing fuel consumption. A number of secondary purposes are mentioned in the paper.

It is this writer's opinion that the most important practical objective among all of the above is to increase the awareness of the officers of potentially dangerous or uneconomical conditions. Hence, it is not enough to call for a system to monitor "wave-induced...stresses, roll, vertical and lateral accelerations" (as at top of p. 278). The primary problem is to decide for each ship the specific responses of interest, such as:

- Lateral acceleration at

bridge or at uppermost level of deck cargo.

- Relative motion between bow and wave, affecting probability of slamming or shipping water.

- Fuel consumption.

Then, sensors must be selected to measure these quantities as directly as possible. See Hoffman and Lewis (1975). For example, lateral accelerometers can give direct indications of the rms response at the locations in the ship where they are critical.

As for relative motion, mention is made on p. 277 of indirect methods of detection. "An alternative method to detect slam and green seas is to strain gage a shell frame in the bow flare and measure the stresses." When the water rises high enough to exert a significant stress on the frame (or an actual wave impact occurs), this impulse can be detected, and the ship's officers can, with experience, relate the frequency of occurrence of such impulses with the occurrence of shipping water and slamming.

Although a vertical accelerometer at the bow may give an indication of the violence of bow motions, and perhaps of the vibratory response to a slam, it is not clear that it has real value to the deck officers of most ships.

Similarly, there is doubt as to the value of measurement of midship stresses (p. 273) as an indicator of hull bending moment. All oceangoing ships are designed to survive any sea conditions they are expected to meet, and the paper warns against attempting to set absolute limits of safe operation anyway. So, why present information to the officer that has no real meaning to him? (As a matter of fact, this sensor is not recommended on p. 281 of the paper.)

The above comments on midship stress do not apply to other ship responses involving motions and accelerations. One of the prime reasons for shipboard instrumentation (on Naval as well as merchant ships) is to make it possible for each master to set his own limits on the basis of experience, and to share his findings with others.

In conclusion, there can be no doubt that carefully planned instrumentation can be a valuable step toward safer and more economic ship operation. I would urge that careful attention be given to the following questions at the time any installation is planned:

- What are the factors affecting safety and economy for this particular ship?

- What specific sensors should be used to monitor these factors as directly as possible?

- How should they be displayed for easy, practical use by the deck officers?

MARK D. NOLL (AM)
U.S. Coast Guard

Visual Motions Sight Box

> "The primary purpose of the monitoring instrument is to provide him (the Master) with reliable information on the 'quantitative level of stress or other response' his vessel is experiencing, since he can not see or feel the response." (pg. 279, para. 1)

In my opinion the Master must "see or feel" the response of his ship. Sensory feedback is very important for verifying any electronic system used aboard ship. For example: the radar, the steering compass and the rudder angle indicator all provide electronic and/or mechanical guidance to the Master. But he also relies on occasional visual confirmation (i.e., sighting of contacts, steering on landmarks and witnessing the swing of his vessel) to assure himself of their dependability and accuracy. Therefore, sensory feedback in addition to a stress and motion monitoring system would be a big plus for returning a "feel" for the vessel to the Master as his vessel labors in a seaway.

Since "Human judgement and responsibility will remain the best overall guarantor of ship safety and operational efficiency for many years to come" (pg. 276, para. 1), each of the monitoring systems mentioned in this report faces possible failure and/or rejection by the crew because

> "The mere addition of a device... cannot prevent a casualty... There is always a danger that such devices may tend to desensitize the user to a point where he would act less prudently." (pg. 266, para. 4)

> "...it becomes much too easy to display excessive and unusable data." (pg. 275, para. 1)

> "Equipment failures (of)...electronic instruments...." (pg. 276, last para.)

—unless a means is provided to visually confirm the accuracy and dependability of the monitoring system. With this, the Master will develop a "feel" both for his vessel and for the data presented by the stress and motion monitor.

A proposed solution could be a device such as the Visual Motions Sight Box (VMSB) shown in Figure 1. The advantages of the VMSB would be (1) simplicity, (2) direct sensory input, (3) Master retains sensitivity to his vessel, (4) no electronic malfunctions or shifts, (5) by presetting cursors in port, he may visually see shifts in mean as fuel and supplies are consumed or as ballast is shifted, (6) periods of oscillation and twisting may be timed, and (7) it would be adaptable to most vessels.

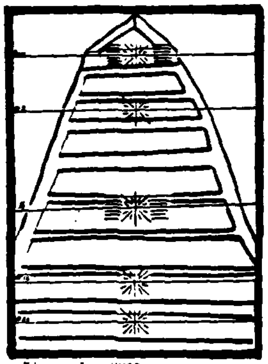


Figure 1 - VMSB
View of ship's bow through VMSB in pilothouse window.

The design of the VMSB would include (1) predetermined "targets" marked on the vessel, (2) movable cursors to allow pre-sailing adjustment of the VMSB with targets, (3) a stopwatch for timing period of oscillations, (4) horizontal and angular divisions on the cursors for sighting relative displacements and twisting, (5) a viewing hood (similar to radar) for consistent sight positioning. With this device, the relative motion of his ship would be discernable through visual stimuli via the VMSB.

The VMSB does not negate the desire to have an effective stress and motion monitoring system. But as the Master begins to relate the computerized output with his visual observations, he will not have to rely on a computer when he is in tight situations and has no time to look at a CRT screen. And as his confidence in the system increases, he will more readily accept the analysis of the monitoring system when visibility is poor and motions are extreme.

The apparent trend, so far, for all of the monitoring systems, may be to give too much scientific data to the Master. The Master is operationally oriented. I re-emphasize the point made in the report:

> "If a monitoring system excludes the sailors ability to relate the information to the overall picture, the result can be worse than before." (pg. 271, para. 4)

Figure 11

It appears that Figure 11 is drawn wrong. The curves should be reversed. "Capability" must be much higher than "Demand" placed on the vessel. Otherwise, the point of intersection, as drawn in this report, is actually the "possibility of success" and not the "possibility of failure."

Voyage Recorder (Pg. 273)

The difficulty with these devices is in determining what exactly will be monitored and recorded. Will commands by the Master be taped? Will sea conditions be measured? Will rpm or speed of advance be recorded? What will all this mean anyway? Ships are quite a bit different than aircraft, and this method has many inherent flaws.

Authors' Closures

Kaare Lindemann:

I believe that the number of discussions given demonstrates a growing interest in the shipborne instrumentation to aid in prudent seamanship. The honesty and constructive criticism shown by the discussers is particularly helpful for those of us who take an active part in the development of such instruments. It seems that the discussers in general show similar concerns and reservations related to shipborne hull monitoring and guidance instruments. I agree that some topics need further investigation and testing before they can be recommended for practical use. However, considering pure response monitoring, the state-of-the-art has, to my belief, reached a conclusive stage and introduction will provide a giant step forward for the master and mates. To illustrate the harmony of the discussers, each representing a different interest in the maritime community, I would like to provide the following plan.

Mr. Fisher would like an instrument to provide information on container constraint forces. This could be achieved by an instrument proposed by Messrs. Boylston and Hammer; simple and reliable as advocated by all investigators, and noted by Professor Lewis, for motions sensitive vessels. The common response is necessary, as stated by Mr. Hammer, to provide familiarity for the masters/mates as they change from vessel to vessel, while also providing a customer optional response. This simple display instrument with two or three responses must be accompanied by training and will be accepted only after years of familiarization; command will remain the responsibi-

lity of the master - Messrs. Bursley, Walburn, Boylston and Hammer.

Such instruments, with varying levels of sophistication, have been installed for commercial use on ten tankers of sizes up to 385,000 DWT: an OBO, an LNG vessel, a containership, two cargo liners and three RO/RO vessels. The first installation was in 1973; each has met with various levels of success. The success level can, however, to a large extent be traced back to the navigator on board the ship who must use the instrument. His interest and understanding of the instrument is crucial to its success or failure.

Hence, only by proper training and education of ship navigators in the principles of seakeeping and application of instruments will they be more likely to consult and use a monitoring instrument. This we have seen during the training program undertaken in Norway. Our conclusion was that if we want a system, even the simplest single gage monitoring instrument, to be used, the navigators must be introduced to its potentials and become aware of its limitations, as noted by RADM Bursley. The following is an example of not having sufficient knowledge.

One navigator with experience from a ship equipped with a simple stress and motion monitoring instrument was participating in one of our training courses. At the beginning of the course he was asked to tell about his experiences with the instrument. In his opinion the instrument was unreliable and could not be trusted, and was consequently turned off. When asked to elaborate, he said that they had observed large differences in the port and starboard longitudinal stress levels measured in the deck at midships. The stresses should, in his opinion, be equal. When told that differences will occur, and this was the reason for using two sensors, he regained confidence in the instrument and, when back on the ship, turned the instrument on.

Messrs. Chen and Dalzell pointed out the use of hull response monitoring to further evaluate the basis of present scantlings, which certainly is of value and is one of the reasons why Veritas is engaged in this research. I note that the sponsors of the Great Lakes stress monitoring effort are planning to install tape recorders during the T&E phase for long-term data collection. VERITAS finds it even more important to engage in this research to retain one of the most important bases for their rules. Scantlings are based on sophisticated theoretical models, but these models are calibrated with in-service experience. Without prudent seamanship, the failure rate due to rough weather would be expected to rise. We can, I believe, expect a decline in the practical experience possessed by ship masters in rough weather operations. Hence, they have a reduced ability to be as prudent. This is not a consequence of less educated and trained navigators, but a consequence of other factors:

- A tendency toward reduced requirements for practical experience at sea before coming to a command position.
- Improved social conditions resulting in shorter time periods at sea and more frequent change of ship types, implying a reduced feel of each ship.
- Weather forecasts are becoming more reliable and cover larger areas, with the result that ships tend to avoid storms and thus the crews gain less experience from ship operations in heavy weather.

In summary, the master of the future will have less experience with the operation of his ship in rough weather. I realize that the crews of Mr. Walburn's Great Lakes vessels and Mr. Boylston's LNG carriers may be highly motivated and well trained, but one or even all of the above factors may apply to their fleets as well. In order to maintain the basis for scantlings, we must insure that prudent seamanship will prevail at the same standards as today. This can be achieved by ship response monitoring instruments.

Dr. Hoffman has criticized our Table 1 and states that it does not give full credit to the development undertaken prior to the ongoing research. In inspecting the table we have found that a lack of credit exists for several programs, and I thank Dr. Hoffman. A revised edition of Table 1 is attached. Yes, I note the differences in the training and education (structured) advocated by the Norwegian programs and that (onboard instruction of the master) advocated by Dr. Hoffman. This difference can also be contrasted with our programs which bring the pupils to a classroom environment as compared to the instructors—usually the engineers who developed the instruments--going to the vessel. I await Dr. Hoffman's publication of results from this form of instruction.

One important and previously controversial aspect of the SO3 project which seems to share general recognization among the three major programs has been correctly cited by Dr. Hoffman. That is the use of seakeeping theory with theoretical wave models (P-M for the SO3, JONSWAP for the BURNS HARBOR and ISSC for the HOLLANDIA) and measured vessel responses to quantify the wave heights

and directions that the vessel is experiencing. This has been adopted due to reluctance on the part of the master, rather than his inability, to estimate the wave environment. I agree with Dr. Hoffman's statement on the advanced features of the BURNS HARBOR instrument which have gained from each of the preceding U.S. (and I hope the Norwegian) programs, and from the active interest and support of the owner, Mr. Walburn.

Finally, I must take the opportunity to thank the United States Coast Guard for the effort of bringing us together to write this paper. Large barriers due to lack of communication have been lowered. I feel like rephrasing Sir Winston Churchill's words from World War II: "look to Norway" to "look to your neighbor and learn from him." In this respect the world is assured of a better product at an earlier stage; a result which will improve safety by the best possible means.

Walter M. Maclean:

Mr. Boylston's remarks are always welcome, particularly in view of his extensive experience with the Ship Structure Committee's full-scale instrumentation on the SL-7, as are Mr. Walburn's, in view of eight years of support of Coast Guard research on the CORT. The latter has aided in the hoisting of computers to the bridge at midnight and the cutting of fifteen holes in the bow of the CORT for underwater pressure measurements. We can assure Mr. Boylston that his concern for the reliability of computers in the shipboard environment need no longer be of primary concern. It does not appear necessary to call for mil-spec or other more rigorous construction standards for the computers in the instruments discussed in this paper. All computers used have been off-the-shelf, commercial systems whose purchase prices have been decreasing yearly. Those used in the ITALIA and FURMAN instruments have given generally excellent service. Under the Norwegian S01 and S03 projects, one computer has provided seven years of service without a problem. In another instance, a sea swept aboard and submerged the computer. Upon disassembly, distilled water washing and reassembly, the unit continued in service without further incident. Questions as to drift, both mechanical and electronic, voltage surges and other problems have yet to be answered.

The remarks of Prof. Lewis concerning the objectives of response instrumentation go to the heart of the issues being addressed: whereas safety is of primary concern from the regulatory/classification point of view, improved economics is of importance to the Maritime Administration and the operators. Further, he points out that the initial problem is to determine the specific responses of interest. For instance, for the ITALIA, the concern was the incidence of cargo damage, resulting, at least in part, from excessive vertical and lateral motions in high sea states; for the FURMAN, slamming and deck wetness and cargo damage forward, and for Mr. Fisher of Matson, the adequate securing of containers on deck.

There is much concern, as stated by Messrs. Bursley, Boylston, Noll and Hammer, as to the extent that such instruments will be accepted and used by ship's officers, who neither understand the complicated details of such instruments nor have the time to do more than learn how to use them. The establishment of training material suitable for self-study aboard ship and supervised instruction in the maritime colleges and academies is required. The S03 project has made this a primary part of the requirements for their research. Final phases of the ITALIA/FURMAN and Great Lakes projects will also. Mr. Lindemann has on occasion spoken of the following categories of ship masters:

- The experienced, confident master who knows his ship route and has "no need" for assistance.
- The experienced but curious master who is interested in these new ideas as a means of doing a better job.
- The master who knows there are problems he can't solve and knows he needs help regardless of his experience.

Experience to date has included all three types. Even the most experienced and confident have come to recognize there is a need for having an instrument that can assess ship performance with the consistency of a master having years of sea time.

Prof. Lewis seems to have incorrectly referred to the survivability of vessels. Perhaps it could be more accurately stated as, "all ocean-going ships are designed to survive any sea conditions they are expected to meet with an acceptable level of risk." That level of risk is, of course, subject to periodic review and revision by the regulatory, classification and underwriting community as experience, public policy and the state-of-the-art change. Thanks to Mr. Noll's attention to detail, Figure 11 should have the demand curves to the left of the capability curve.

H. Paul Cojeen and Edward A. Chazel, Jr.:

We thank Mr. Walburn for his active interest, continued understanding and enthusiastic support both as an operator and fellow researcher. We further call

Messrs. Bursley and Boylston's attention to his pioneering efforts to propose a compromise in the alert/warning/limits problem. Mr. Walburn insisted that the instrument on the BURNS HARBOR be provided with a variable alert that the master sets. We agree that this will permit the master to use the instrument to gain experience and communicate this among his mates. This may ease their concerns re use of the instrument as a crutch, by placing the responsibility of alert levels in the hands of the master where it belongs.

RADM Bursley has correctly noted that the NTSB recommendations following the loss of the TEXACO OKLAHOMA were the first U.S. mandate for hull monitoring research. For this and his efforts to address this subject, we are grateful and in full concurrence with all his comments. The Commandant of the Coast Guard, in a recent address (1) to the American Petroleum Institute, offered the following thoughts:

> "Ships have never been and probably never will be failure proof...We have not adequately recognized the sailors' part in the system. Our ships are large, capital intensive and operated on tight schedules by many with less experience than their predecessors...The motions of larger ships, which are masked to the human sensations can be measured by electronic means... here's (response instruments) an area which shows promise as a reliable way to back up the sailors' traditional sixth sense..."

Mr. Hammer has provided a crystal clear summary of our paper and our intentions, and probably an even longer-lasting legacy by undertaking the establishment of a SNAME panel on ship instrumentation.

To Messrs. Boylston, Fisher and Walburn and Bursley, we would like to draw attention to a recent report (2) by Glansdorp of the Netherlands in which he suggested that an owner or operator must assume substantial risk when making economically oriented decisions on routing of vessels.

We further dedicate a portion of our time to translating our engineering rigor into more and effective vigor, to help the masters and mates who sail their vessels on the world's oceans. This end seems to have been lost in our constant striving for rigor. We invite others who possess greater knowledge of the response of vessels to also provide some vigor.

References:

1. Hayes, J. B., ADM, Address to American Petroleum Institute, Coronado, California, May 1980, Commandant's Bulletin, U.S. Coast Guard, 23-80, June 2, 1980.

2. Glansdorp, C. C., "Round the Horn or Through Magellan," Netherlands Maritime Institute, Report Number: R109.

ATE

LME